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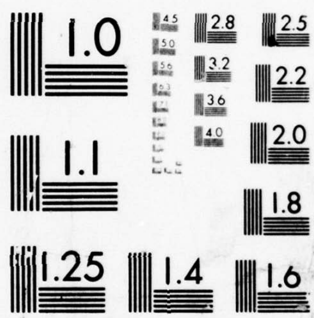

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ALTERNATE SUBSONIC LOW-COST ENGINE

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
111 S. 34th STREET, P.O. BOX 5217
PHOENIX, ARIZONA 85034

MAY 1978

FINAL REPORT APRIL 1976 TO DECEMBER 1977

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This document presents the final report on the research and development of a turbojet derived from low-cost, high-production turbocharger components and an augmentor based on a low-cost, ramjet sudden-expansion burner. The engine, designated AiResearch ETJ131 Model 1030, is an afterburning derivative of the AiResearch ETJ131 engine. Changes to the basic ETJ131 included placing the combustor parallel to the engine center- over

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20. ABSTRACT (Cont.)

line, incorporating aerodynamic changes to accommodate the additional airflow required to achieve the thrust goal for the Model 1030, and adding an afterburner.

FOREWORD

This report describes the development effort completed on a small, low-cost, subsonic afterburning turbojet engine. This program was conducted for the United States Air Force, Aero Propulsion Laboratory under Contract F33615-76-C-2063, Project Number 3012. The program was accomplished by the AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, located at 111 South 34th Street, Phoenix, Arizona 85034.

SYMBOLS

PARAMETERS

PTS	Points
PCT	Percent
F_N	Net thrust, lbf
LBF	Pounds-force
LBM	Pounds-mass
TSFC	Thrust specific fuel consumption, lbm/hr-lbf
L/D	Length-to-diameter ratio
V	Velocity, FPS
d	Diameter, in.
P	Pressure, psia
T	Temperature, °R
A	Area, $in.^2$
M	Mach No., dimensionless
η	Efficiency, dimensionless
Δ	Difference
F/A	Fuel-to-air ratio, lb fuel per sec per lb air per sec
δ	$P_t/14.696$
θ	$T_t/518.69$
N	Rotational speed, rpm
C_F	Thrust coefficient, dimensionless
C_D	Discharge (flow) coefficient, dimensionless
W	Flow rate, lb/sec (air), lb/hr (fuel)
g	Gravitational constant, 32.174 ft-lbm/sec^2-lbf
C_P	Specific heat of air at constant pressure, btu/lb-°R
C_V	Specific heat of air at constant volume, btu/lb-°R
γ	C_P/C_V
R	Gas constant for air, 53.345 ft-lbf/lbm-°R
P_r	Pressure ratio

SUBSCRIPTS

0	Engine Station:	Ambient, bellmouth inlet
1	Engine Station:	Bellmouth throat, compressor housing inlet
2	Engine Station:	Compressor rotor inlet plane
2	Engine Station:	Compressor discharge (scroll)
3.1	Engine Station:	Combustor plenum
4	Engine Station:	Combustor discharge, turbine inlet (torus)
5	Engine Station:	Turbine rotor exit plane
6	Engine Station:	Turbine exhaust flange plane
6.1	Engine Station:	Augmentor duct immediately upstream of sudden expansion plane
7	Engine Station:	Augmentor duct immediately downstream of sudden expansion plane
7.1	Engine Station:	Exhaust nozzle entrance
8	Engine Station:	Exhaust nozzle exit plane

c	Compressor, combustor
AB	Afterburner
N	Net (thrust)
OV	Overall
f	Fuel
t	Total, top
S	Static
T	Turbine
LO	Lubricating oil
a	Air
G	Gross (thrust)
M	Measured (thrust)
D	Ram drag
b	Bottom

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SECTION I

INTRODUCTION

This document, submitted by the AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, presents the final report on the research and development of a turbojet derived from low-cost, high-production turbocharger components and an augmentor based on a low-cost, ramjet sudden-expansion burner. The program was conducted for the United States Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, and is authorized under Contract F33615-76-C-2063, Project Number 3012. This program was conducted from 1 April 1976 through 31 December 1977.

The engine, designated AiResearch ETJ131 Model 1030, is an afterburning derivative of the AiResearch ETJ131 engine that was designed and tested under Air Force Contract F33615-76-C-2072. Changes to the basic ETJ131 included placing the combustor parallel to the engine centerline, incorporating aerodynamic changes to accommodate the additional airflow required to achieve the thrust goal for the Model 1030, and adding an afterburner.

SECTION II

RESULTS AND CONCLUSIONS

The program described in this report was a twenty month effort to design, fabricate, and test a low-cost augmented turbojet engine. The AiResearch ETJ131 Model 1030 was derived from the AiResearch Model T18A turbocharger. Turbocharger production at the AiResearch Industrial Division is currently 400,000 units per year. The design effort with respect to the basic engine, consisted of two tasks--combustor design and turbine housing design.

The combustor designed for the ETJ131 Model 1030 was a production configuration integral welded assembly, positioned parallel to the centerline of the engine. The welded assembly was consistent with the low-cost goal of the engine design.

The basic T18A turbocharger turbine housing was redesigned to accomodate the higher turbine inlet temperature and mass flow of the ETJ131 Model 1030. The material was changed from GMR 235 to Hastelloy X. The design, however, was similar to the standard production housing to ensure that the same high production rate and low cost could be achieved.

The design task also included the design of an augmentation system based on concepts proven in an Air Force sponsored program that investigated sudden expansion or dump burners for ramjet applications (see List of References). The afterburner design selected for demonstration was a simple low-cost configuration utilizing a silicon elastomer (Dow Corning 93-104) ablative protective liner in the combustion zone and an uncooled silicon carbide coated graphite nozzle.

Prior to fabrication of the demonstration augmentor, a water-cooled augmentor was designed and fabricated to be tested on the basic ETJ131. This testing provided an early demonstration of the dump combustor concept, and provided experience with it's operational characteristics. Data from these tests was evaluated prior to release of the Model 1030 augmentor system for fabrication.

Testing of the ETJ131 Model 1030 included engine checkout, main combustor development testing, and demonstration under simulated ram conditions. The combustor tests were conducted in the AiResearch combustion test facility using simulated engine airflow conditions.

Following the combustor development tests, the unaugmented engine was assembled and installed in the AiResearch Altitude Test Facility. The first series of runs were conducted at sea-level static conditions. Engine airflow was taken from cell ambient and avoided the corrections necessary when testing at ram conditions. The agreement between predicted and tested data at this condition was extremely good. The engine developed 131 pounds of thrust at a thrust specific fuel consumption of 1.6 pounds-per-hour-per-pound.

After successful completion of the sea-level static testing of the basic engine, the augmentor was installed and demonstration testing began. A series of tests were made, including testing with the afterburner installed but not operating, and testing with the afterburner lit. Approximately 47 minutes of operation were logged with the afterburner installed. Of this 47 minutes, there were approximately 6 minutes of operation with the afterburner lit. Testing was terminated when a portion of the afterburner ablative liner separated from the metal case.

Performance testing had not been completed when the malfunction occurred, however, sufficient data was acquired to refine the performance prediction model. Correlation between measured data and predicted performance is good and the results of the testing indicate that the thrust goal of 200 pounds of thrust at Mach 0.7, sea level can be achieved.

Further development of the augmentor ablative liner is required. The total time of six minutes is significantly longer than the 30 minute objective. The life consumed while operating at non-augmented conditions cannot be quantified. Recent developments in ramjet technology offer attractive means of improving the integrity of the ablative liner.

This program successfully demonstrated the feasibility of adding an augmentor to a low-cost turbojet and also further demonstrated the feasibility of using a low-cost turbocharger as the basis for a propulsion engine. Notable accomplishments of the program were:

- Demonstrated augmentor efficiency levels of 88 to 92 percent.
- Smooth stable light-off and operation of the augmentor.
- Turbine life exceeding one hour at turbine inlet temperatures of 1800 to 1900°F.
- Successful operation of a parallel type combustor.
- Demonstrated ability of the ablative liner to protect the metal case.

Areas needing further development include:

- Improved retention of the ablative liner
- Improved turbine efficiency
- Decreased primary combustor pressure drop
- Improved afterburner nozzle flange design

SECTION III

TECHNICAL DISCUSSION

The objectives of this program were to design, fabricate, and test a turbojet engine derived from low-cost, high-production turbocharger components and an augmentor based on a low-cost, ramjet sudden-expansion burner. The program goals for the ETJ131 Model 1030 were:

- Cost (Projected) - \$2000/engine (Lots of 1000)
- Thrust (M=0.7, S.L.) - 200 pounds
- TSFC (M=0.7, S.L.) - 3.0 lb/hr/lb
- Life (M=0.7, S.L.) - 30 minutes
- Weight - 100 pounds
- Volume - 3.0 ft^3
- Frontal Area - 1.2 ft^2
- Storage Life - 5 years

The program was separated into three tasks. These tasks were:

I - Design, Procurement, and Fabrication
II - Development Testing
III - Demonstration

AiResearch divided Task I into three elements. They were:

Task IA - Test Engine Design
Task IB - Production Engine Design
Task IC - Fabrication and Procurement

The following sections describe the work performed and results obtained in each of the tasks and task elements.

1. TEST ENGINE DESIGN - TASK IA

Task IA addresses the design of a demonstrator version of the proposed engine. The demonstration engine did not incorporate

- Fuel Control
- Fuel delivery system
- Lubrication system
- Starting system

Also, elements of the engine were not flight weight designs. In most instances, demonstration of flight weight designs were beyond the scope of this program.

a. Engine Cycle Definition

An in-depth review of the engine design was completed and pre-existing baseline cycle assumptions were checked and verified, as required, early in the program. Table 1 is a summary of the cycle changes showing the baseline and the values as redefined at this point in the program. The effect of the changes on thrust and specific fuel consumption are also shown. At 200 pounds thrust, the cycle has an estimated specific fuel consumption of 3.07. Production margin is included in the performance estimates. Each of the cycle changes is discussed below.

(1) Turbine Efficiency

The compressor proposed for the Model 1030* requires a 1.99 total-to-total pressure ratio at a corrected flow of 1.989 pounds per second. The flow requirements exceed those currently available with the existing T18A turbocharger hardware. It was

*Hereinafter reference to the ETJ131 refers to the turbocharger turbojet developed under Contract F33615-76-C-2072 and Model 1030 refers to the afterburning engine being developed under this program.

TABLE 1. REVISED ENGINE CYCLE VERSUS THE BASELINE CYCLE FOR THE ETJ131 MODEL 1030, AT SEA LEVEL, MACH 0.7, STANDARD ATMOSPHERE.

Parameter	Baseline	Revised	Resulting % Change In F_N	Resulting % Change In TSFC
Turbine Efficiency Change, Points	Base	-2.6	- 2.4	+2.5
Mechanical Losses, HP	0	15	- 3.1	+3.6
Combustor Efficiency	0.98	0.99	0	-0.5
Compressor Corrected Flow, Lb/Sec	2.613	2.880	+10.5	-0.3
Compressor Pressure Ratio	3.200	3.311	+ 1.0	-0.9
Compressor Efficiency Change, Points	Base	+3.5	+ 4.3	-4.2
Augmentor Temperature, °F	2864	2720	- 3.6	-3.3
Augmentor Efficiency	0.90	0.92	0	-1.2
Production Margin, PCT	0	6.0	- 6.0	+6.0
Net Change			+ 0.7	+1.7

proposed to design and fabricate a larger turbine housing to accommodate the higher turbine inlet temperature of the engine. The turbine redesign was expanded to include increasing the flow size to match a higher flow compressor that became available after contract award. Efficiency and weight penalty is associated with the higher flow turbine housing, but it is offset by increased compressor performance. Preliminary design of this new, larger turbine housing indicated that the efficiency should be 2.6 points lower than assumed in the proposal.

(2) Mechanical Losses

The proposal assumed that mechanical losses, e.g. bearing losses, were included in the turbine efficiency. The review corrected this error and appropriate mechanical losses were added.

(3) Combustor Efficiency

A review of the main combustor design indicated that the proposal estimate of combustion efficiency was too low. Based on AiResearch experience with small combustors, a combustor efficiency of 0.99 is achievable.

(4) Compressor Flow, Pressure Ratio, and Efficiency

Subsequent to the submittal of the proposal, test data on a new series of turbocharger compressors became available. These compressors offered higher flow and pressure ratio at higher efficiency and increased surge margin. These compressors were introduced into production turbochargers. The PX-1 compressor was selected for the Model 1030 because it provided a thrust increase of approximately 16 percent and decreased specific fuel consumption approximately 5.4 percent.

(5) Augmentor Temperature

Augmentor temperature is set by the 200-pounds thrust requirement. The net effect of cycle changes discussed above is an improvement in thrust. Therefore, augmentor temperature was reduced to a level consistent with 200 pounds of thrust.

(6) Augmentor Efficiency

Augmentor (dump combustor) efficiency was increased from 0.90 to 0.92 as a result of preliminary design studies.

Characteristics of the Model 1030 at the design point of Sea Level, Mach 0.7, Standard Day, are shown in Table 2.

TABLE 2. ETJ131 MODEL 1030 DESIGN-POINT CHARACTERISTICS AT SEA LEVEL, STATIC, STANDARD DAY.

Characteristic	Value
Corrected Inlet Airflow, lb/sec	2.88
Compressor Pressure Ratio	3.31
Turbine Inlet Temperature, °F	1900
Afterburner Inlet Gas Temperature, °F	1622
Afterburner Inlet Gas Pressure, psia	30.82
Primary Combustor Fuel Flow, lb/hr	311.6
Afterburner Fuel Flow, lb/hr	406.0
Net Thrust,* lb	201
Thrust Specific Fuel Consumption,* lb/hr/lb	3.072
Engine Rotor Speed, rpm	72,073

*Includes production margin

b. Off-design Engine Performance

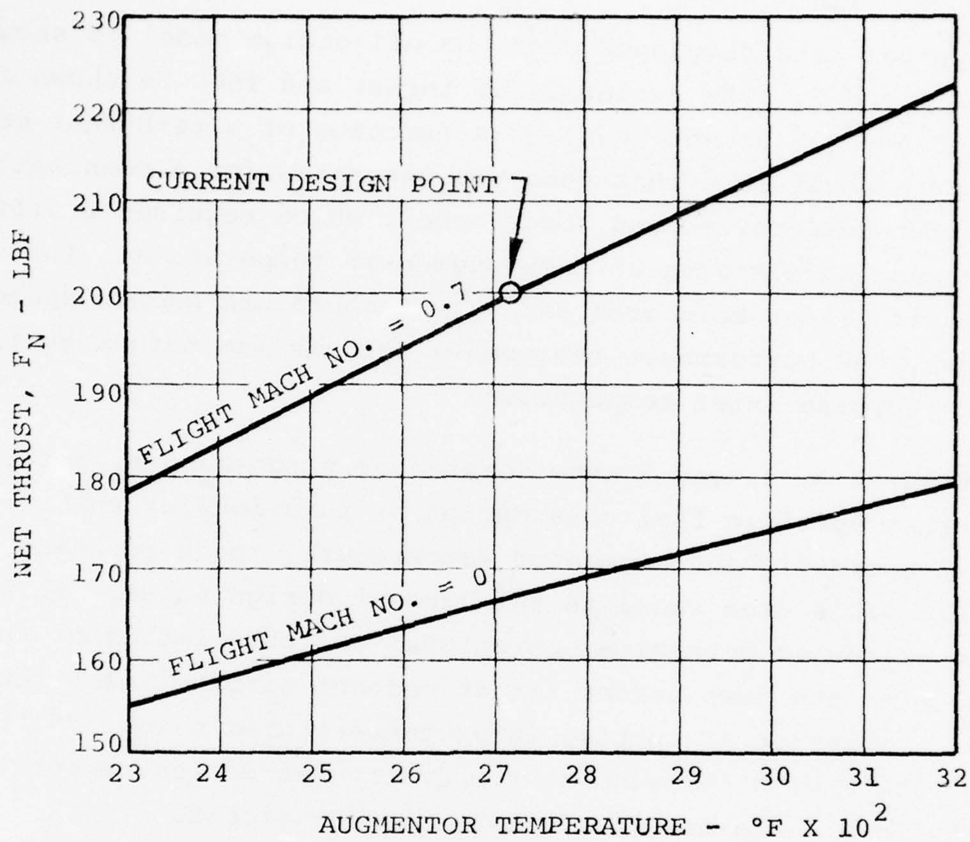
An off-design thermodynamic model was prepared to allow the calculation of engine operating characteristics at conditions other than the design. This data was required for engine design and eventually for testing.

Typical data developed with the off-design model is shown in Figures 1 and 2. The variation of thrust and TSFC is shown for Mach 0.0 and 0.7 at sea level as a function of afterburner combustion temperature. This data was generated for a constant turbine inlet temperature and rotor speed, which requires a different exhaust nozzle area at each augmentor temperature. The alternative is to hold area and vary temperature and/or speed. As shown, the performance represents the maximum thrust available at each turbine inlet temperature.

Figures 3, 4, and 5 show compressor surge margin, net thrust, and thrust specific fuel consumption as functions of turbine inlet total temperature and augmentor temperature, for a constant exhaust nozzle area equal to the current design value. This data was generated to determine operational characteristics of the engine with the dump burner lit at reduced turbine inlet temperatures. Operation at turbine inlet temperatures below 1750°F and above 1500°F with the augmentor operating at design temperature results in a surge margin of less than 10 percent.

c. Turbine Housing Design

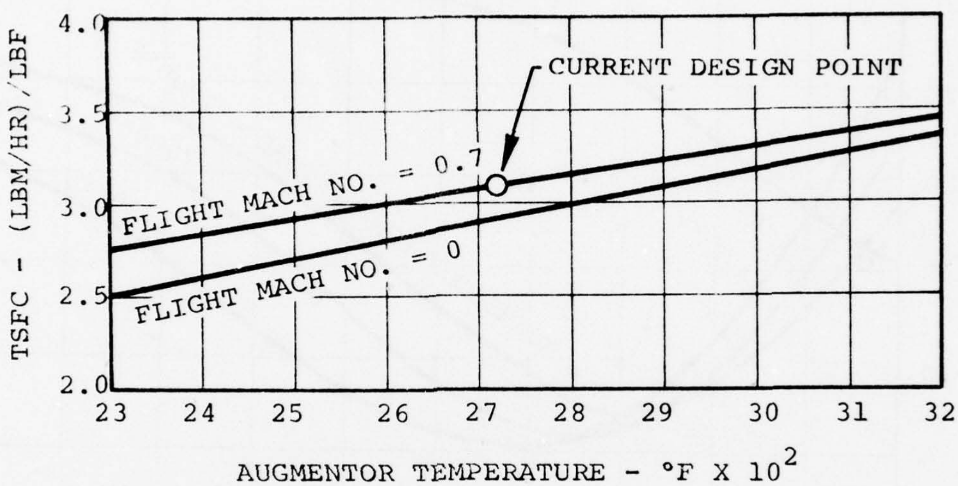
In the explanation of the turbine efficiency change, the background of the turbine housing design was given. The design work involved increasing the minimum cross-sectional flow area of the turbine volute and changing the material from GMR235 to Hastelloy X. Preliminary sizing calculations indicated that an increase in area of approximately 30 percent was required for the higher turbine flow. Efficiency for the larger turbine housing was estimated to be 2.6 points lower than previously assumed.



NOTES:

1. SEA-LEVEL, U.S. STANDARD ATMOSPHERE
2. FUEL LOWER HEATING VALUE = 18,400 BTU/LBM
3. ENGINE ROTOR SPEED = 72,073 RPM
4. TURBINE INLET TOTAL TEMPERATURE = 1900°F

Figure 1. Effect of Augmentor Temperature and Flight Mach No. on Net Thrust.



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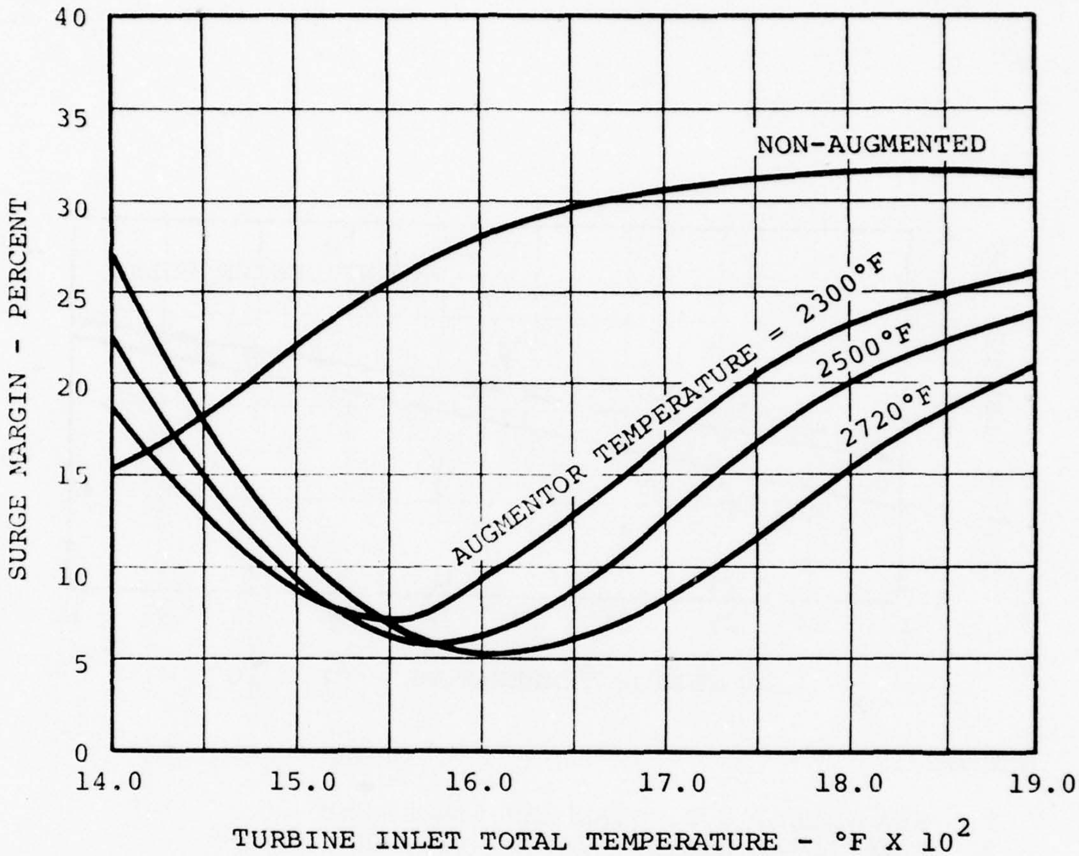
3. ENGINE ROTOR SPEED = 72,073 RPM
4. TURBINE INLET TOTAL TEMPERATURE = 1900°F

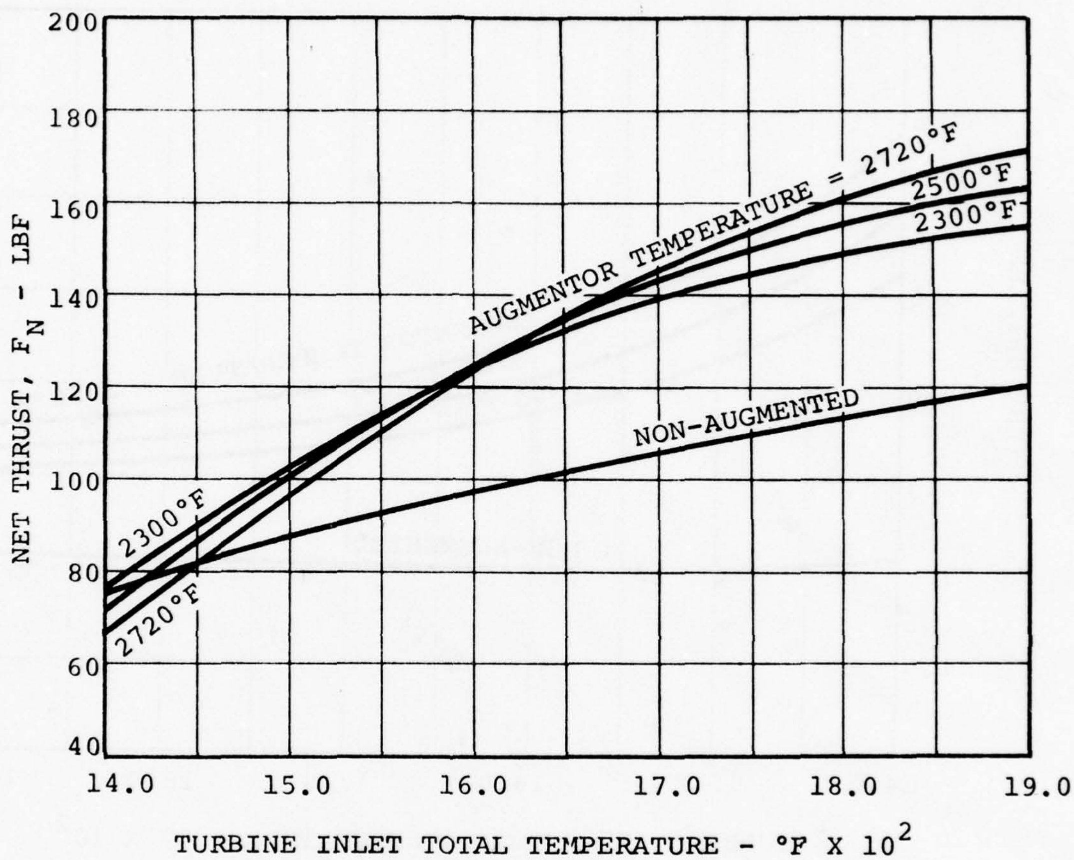
Figure 2. Effect of Augmentor Temperature and Flight Mach No. on TSFC.



NOTES:

1. SEA-LEVEL, STATIC, U.S. STANDARD ATMOSPHERE
2. CONSTANT EXHAUST NOZZLE AREA = 16.14 SQUARE INCH (HOT AREA)

Figure 3. Effect of Turbine Inlet Temperature and Augmentor Temperature on Surge Margin.



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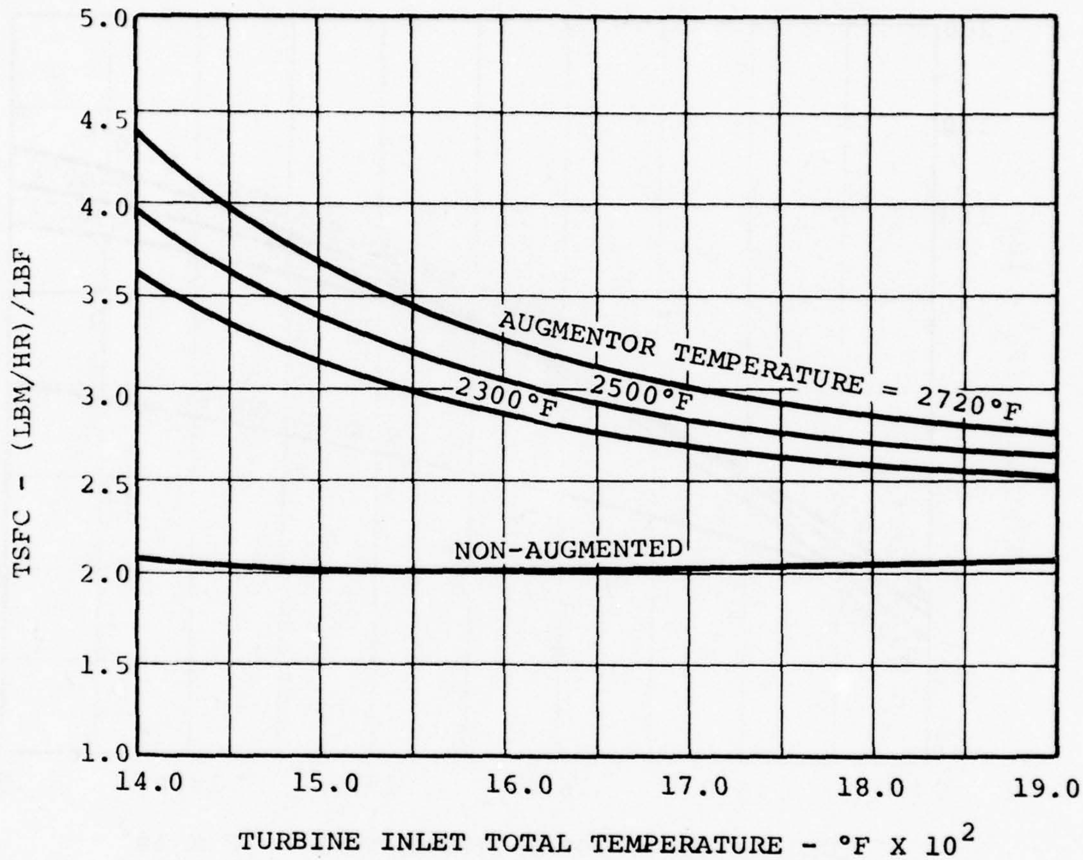
3. CONSTANT EXHAUST NOZZLE AREA = 16.14 SQUARE INCH (HOT AREA)

Figure 4. Effect of Turbine Inlet Temperature and Augmentor Temperature on Net Thrust.



NOTES:

1. SEA-LEVEL, STATIC, U.S. STANDARD ATMOSPHERE
2. FUEL LOWER HEATING VALUE = 18,400 BTU/LBM
3. CONSTANT EXHAUST NOZZLE AREA = 16.14 SQUARE INCH (HOT AREA)

Figure 5. Effect of Turbine Inlet Temperature and Augmentor Temperature on TSFC.

d. Augmentor Design

This section discusses the preliminary design of the augmentor for both the ETJ131 and the Model 1030. In order to maintain design simplicity and the low-cost criteria, the augmentor design selected for the Model 1030 was a sudden-expansion burner. The sudden-expansion burner relies on the rapid increase in flow area to create a recirculation zone to stabilize the combustion process. This type of burner aerodynamically stabilizes the flame, whereas conventional turbojet augmentors use more costly mechanical flame holders to stabilize the flame, A simplified visualization of the augmentor flow field is shown in Figure 6.

Structurally the augmentor can be fabricated from Hastelloy cylinders. The inside of the main burner is coated with an ablative liner to protect the walls from the hot combustor gases. The fuel injector system consists of flush orifices located in the inlet section and will be described in more detail later in this section.

The design procedure includes both empirical relations and analytical design techniques. The empirical relations were developed by the Air Force after conducting extensive parametric studies on sudden-expansion burners. The studies and the results are given in References 1, 2, and 3. Also additional information was obtained from the investigations, F. D. Stull and R. R. Craig, via a personal communication. The analytical design tool utilized was a two-dimensional (2-D) combustor performance model. Since the sudden-expansion burner is symmetrical, the 2-D assumption is valid. The model predicts the augmentor flow field, along with the fuel concentration profiles, temperature distribution, and streamlines.

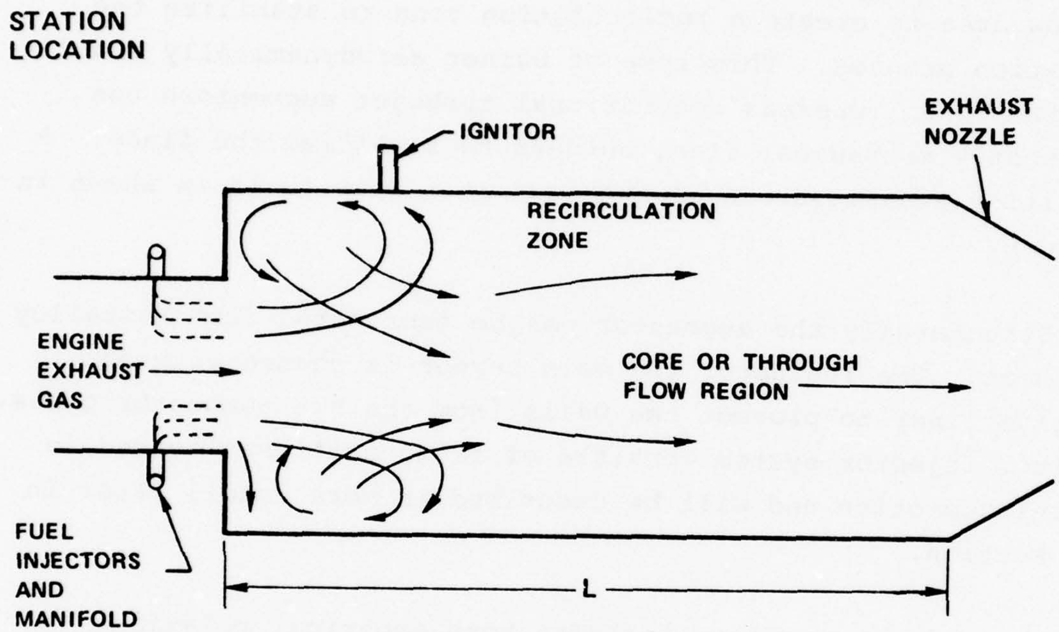


Figure 6. Augmentor Flow Field.

In order to obtain early experience in designing and operating the augmentor, a water-cooled augmentor was designed for the existing ETJ131 engine. By testing the augmentor early in the program it was hoped to identify any problems, such as ignition and instability, and to gain confidence in the design techniques. It was desirable that the augmentor for the ETJ131 be operated over approximately the same range of conditions as the augmentor inlet conditions for the Model 1030. Table 3 lists the augmentor inlet conditions for both engines and as can be seen, the inlet conditions are quite similar. It should be noted that these were the inlet conditions as they were defined early in the program.

(1) <u>ETJ131 Augmentor</u>

Several different diameter augmentors were studied for the ETJ131 application. Starting with an inlet diameter of 4.47 inches, it was found that a diameter of 6.5 inches was best based on combustor efficiency and stability criteria. Three different length augmentors were evaluated with length-to-diameter ratios (L/D) of 3.50, 4.25, and 5.50. Table 4 characterizes the augmentor operating parameters as compared with the empirically derived parameters from References 1, 2, and 3. As can be seen from Table 4, the dump Mach number of 0.15 is within the operating limits of 0.1-0.26 and the loading parameter of 2.337 is well below the maximum of 7. The operating limits, or design criteria, were established by Air Force work as a region where relatively high combustion efficiency existed along with stable combustion.

The 6.5-inch diameter augmentor was analytically evaluated by the 2-D combustor model and the results are shown in Figures 7, 8, and 9. Figure 7 shows the predicted streamlines (lines of constant net mass flow). The recirculation zone is shown at the step change in area, and the contour of the recirculation zone is defined by the maximum inlet streamline of 2.37 lbm/sec.

TABLE 3. AUGMENTOR INLET CONDITIONS FOR ETJ131 AND MODEL 1030 ENGINES.

Condition	ISA Sea Level Static	ISA Sea Level Mach 0.7
W_a, airflow rate (pps)	2.32	3.86
W_f fuel, flow rate (pph)	168.5	356.0
$P_{t6.1}$, pressure (psia)	21.9	31.1
$T_{t6.1}$, temperature (°R)	1889	2095
$D_{6.1}$, inlet diameter (in.)	4.47	4.70
$V_{6.1}$, inlet velocity (fps)	678	859
$M_{6.1}$, inlet Mach number	0.318	0.383

TABLE 4. ETJ131 PRELIMINARY AUGMENTOR DESIGN.

Parameter	ETJ131 Dump Combustor
$D_{6.1}$, Inlet Diameter (inches)	4.47
$V_{6.1}$, Inlet Velocity (fps)	678
D_7, Dump Diameter (inches)	6.5
V_7, Dump Velocity (fps)	320
M_7, Design Mach Number	0.15
L, Augmentor Length (inches)	22.75, 27.63, 35.75
$L/D_{6.1}$	3.50, 4.25, 5.50
$\left(\frac{V_{6.1}}{d_e}\right)\left(\frac{14.7}{P_{t7}}\right)\left(\frac{1000}{T_{t7}}\right)^{1.5}\left(\frac{12}{1000}\right)$	2.337
$A_7/A_{6.1}$	2.11

Design Criteria

$0.10 \leq M_7 \leq 0.26$

$2.0 \leq A_7/A_{6.1} \leq 4.0$

$$\frac{V_{6.1}}{d_e}\,\frac{14.7}{P_{t7}}\,\left(\frac{1000}{T_{t7}}\right)^{1.5}\,\frac{12}{1000} \leq 7$$

$\eta_c \geq 0.9$

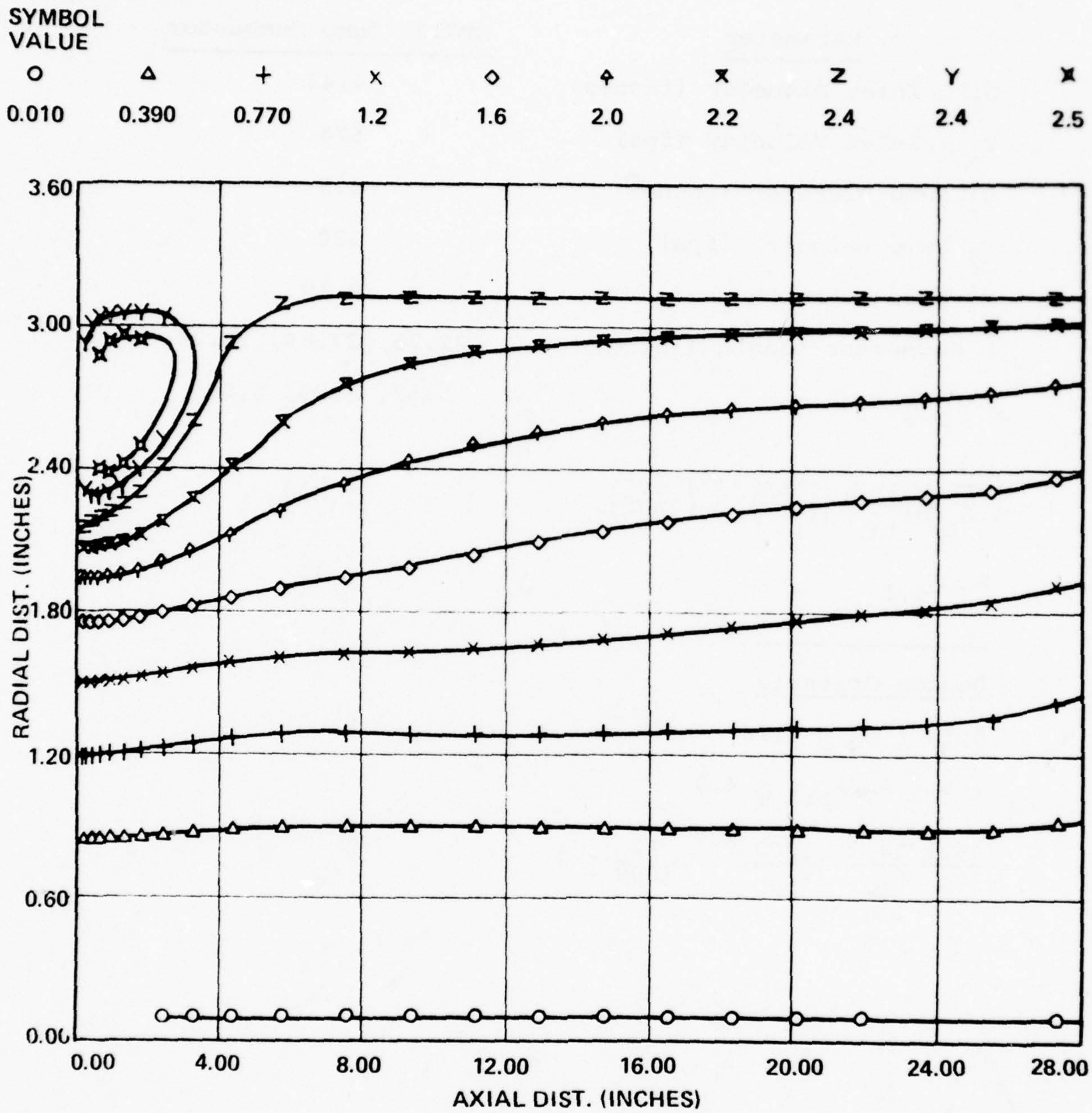


Figure 7. 6.5-Inch Augmentor for ETJ131 (Streamlines - lb/sec).

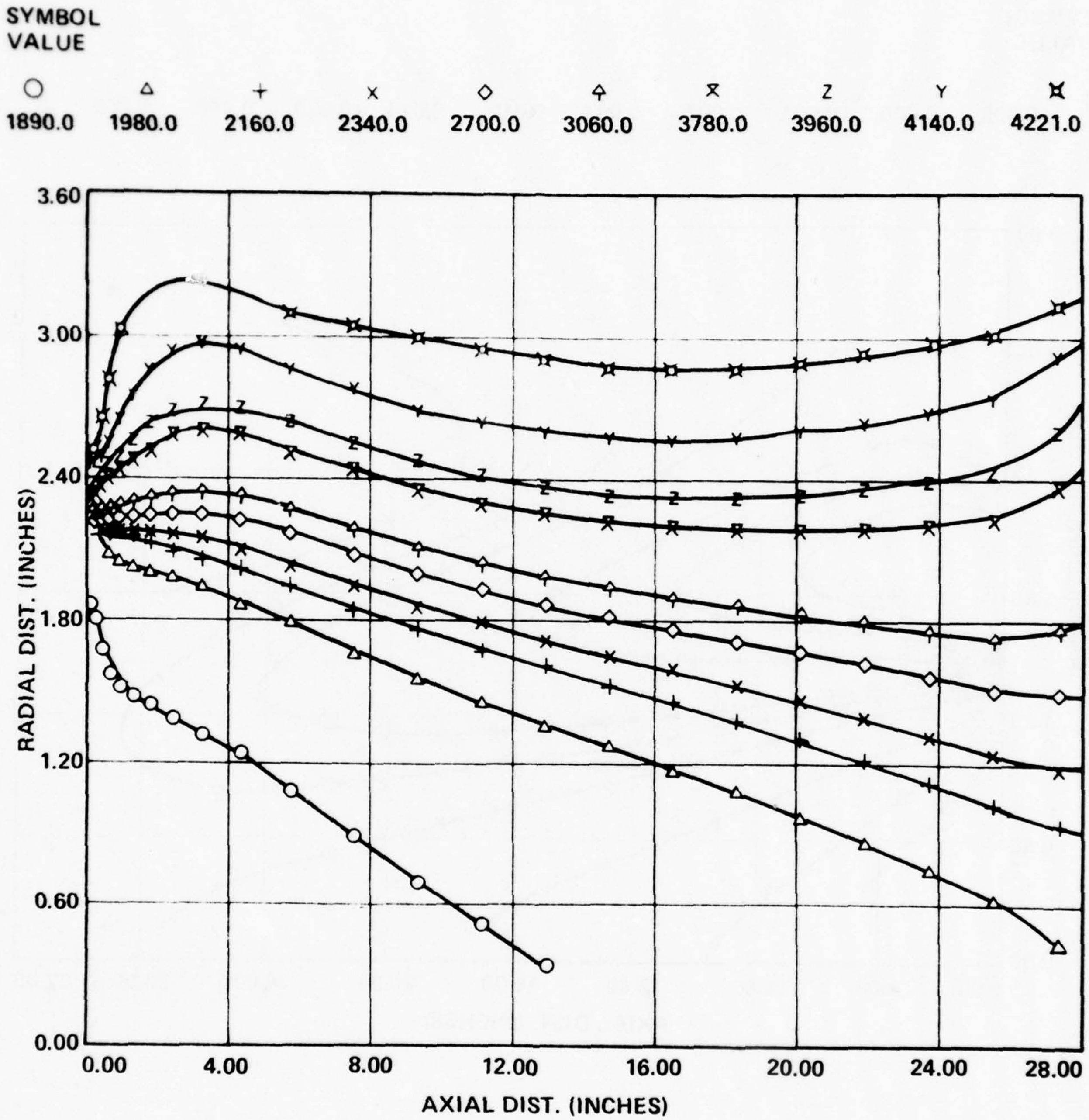


Figure 8. 6.5-Inch Augmentor for ETJ131
(Isothermal Lines - Deg. R).

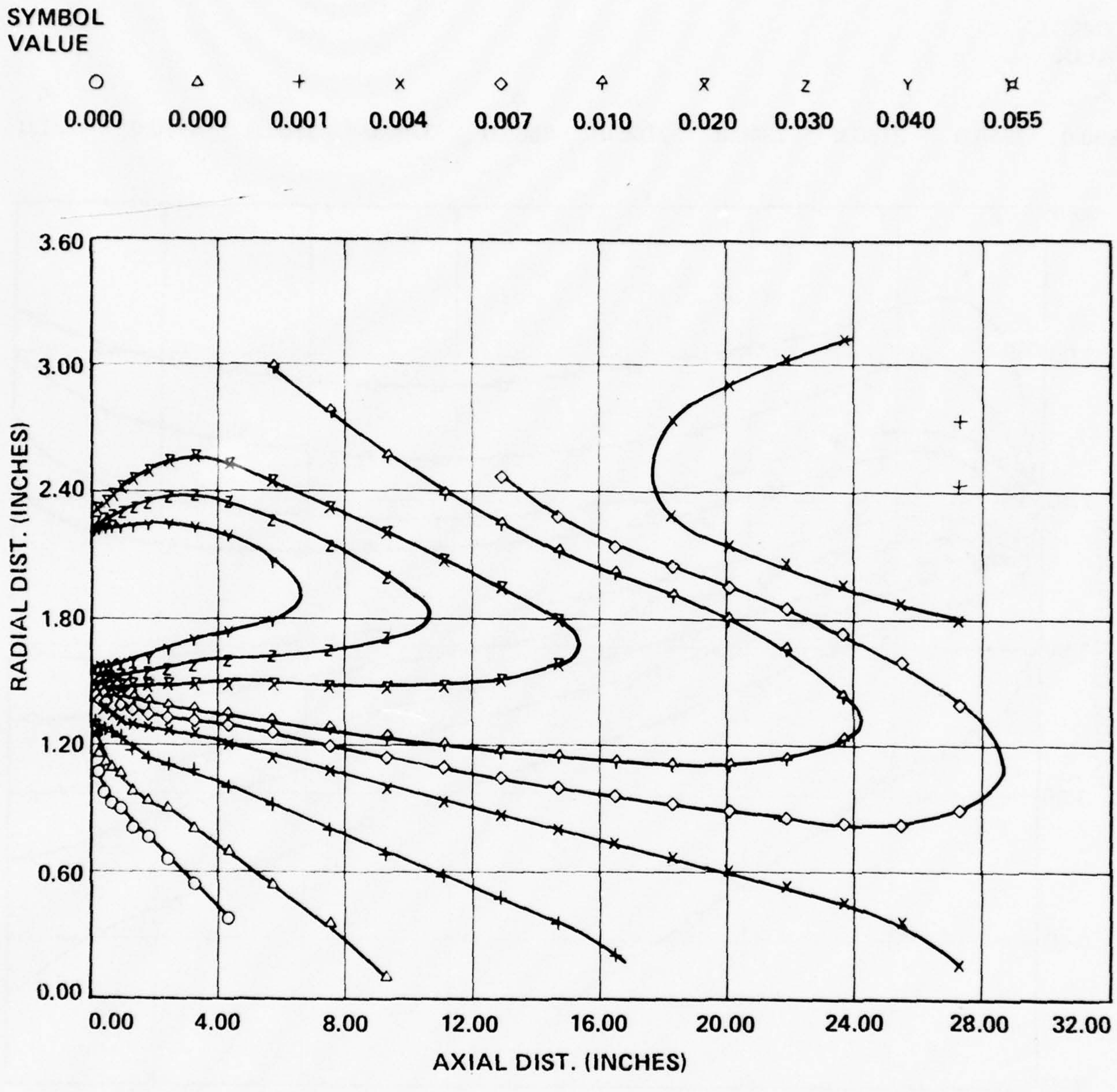


Figure 9. 6.5-Inch Augmentor for ETJ131 (Isofuel Fraction Lines).

The isothermal lines, as presented in Figure 8, show that the highest temperature existed near the combustor wall and declines as the centerline is approached. The point of maximum temperature will occur in the recirculation zone. As the core flow entrains the hot combustor gases from the recirculation zone, the fuel in the core will be ignited. This procedure progresses in toward the centerline of the augmentor causing the temperature to rise to higher levels as the flow moves along the combustor. From Figure 9, which shows the predicted isofuel fraction lines, it is evident that not all the fuel is consumed in the recirculation zone and the core flow. For the L/D of 4.5, the design tabulations from which Figure 9 was prepared show that 13.4 percent of the fuel did not burn resulting in a combustion efficiency of 86.6 percent. Increasing the augmentor length with attendant increase in residence time would result in an increased combustion efficiency.

The fuel injector system requirement, other than injecting the fuel properly, was to be low in cost. This required the injector itself to be simple and also low fuel pressure to eliminate a costly high-pressure fuel pump. The fuel system selected for the augmentor was similar to the system used in the Air Force dump-combustor studies. Eight flush-mounted orifices were located in 45-degree increments around the inlet section upstream of the step change in area. The proper size orifice and upstream placement was determined from the empirical relations presented in Reference 4. The fuel penetration or radial distance the fuel travels was predicted by:

$$\frac{X}{do} = 2.1\left(\frac{P_j \ V_j^{\,2}}{P_a \ V_a^{\,2}}\right)^{.5}\left(\frac{Z}{do}\right)^{.27}$$

where ρ = density (lbm/ft^3)

V = velocity (ft/sec)

X = penetration distance (in)

Z = downstream distance from the point of injector parallel to the air stream axis (in)

do = orifice diameter (in)

The circumferential expansion of the fuel jet (spread) is determined from the following equation.

$$Y/do = 6.95\ (Z/do)^{.33}$$

where

Y = spread distance, width of fuel spray (in)

By combining the equations for fuel penetration and spread a relation for the local fuel/air ratio (F/A) can be derived. The local F/A is the value at a particular axial location downstream of the injection part and is given by the following equation.

$$(F/A)_{\eta} = (F/A)_{\infty} \left(\frac{A_{inlet}}{14.6\ d_o^{\,2}}\right)\left(\frac{P_a V_a^{\,2}}{P_j V_j^{\,2}}\right)^{.5}\left(\frac{Z}{do}\right)^{-.6}$$

where

A_{inlet} = area of the inlet (in^2)

$(F/A)_{\infty}$ = overall fuel/air ratio

$(F/A)_{\eta}$ = local fuel/air ratio

For a given fuel flow it is possible to determine the optimum orifice diameter and location using the equations for penetrations, spread, and local fuel/air ratio. An evaluation of the effect of orifice diameter on fuel pressure, fuel jet spread and penetration, and local fuel/air ratio was conducted and the results are shown in Figures 10, 11, and 12. Based on the Air Force work, the optimum fuel penetration at the point of the step change in area was 16 percent of the inlet diameter for maximum entrainments of the fuel in the recirculation zone. From the figures it is evident that there is a trade-off between spread and penetration. The larger diameter orifices produce more spread, which indicate a good circumferential fuel distribution, but the penetration is relatively low. It should be noted that the smaller orifices result in excessively high fuel pressures and also the point of injection can not be located a long distance upstream of the area step change as this will increase the length of the inlet section and increase the engine weight. From the study, the best combination of orifice size and location was eight orifices of 0.030-inch diameter located 3.75-inches upstream of the area change. Although the penetration is slightly greater than 16 percent of the inlet diameter, the spread is large enough to produce adequate circumferential distribution and the local fuel/air ratio is slightly greater than stoichiometers ensuring good stability.

The igniter system selected for initiating combustion in the augmentor is a simple automotive spark plug located through the side of the augmentor downstream of the step change in area. The axial location was determined based upon the region of maximum fuel concentration adjacent to the augmentor wall, as predicted by the 2-D combustor model. The optimum location predicted was 1.6-inches downstream of the area change. The spark plug was inserted so that the electrode protruded slightly beyond the inner surface of the augmentor wall. Figure 13 represents an overall schematic of the augmentor to be tested on the ETJ131.

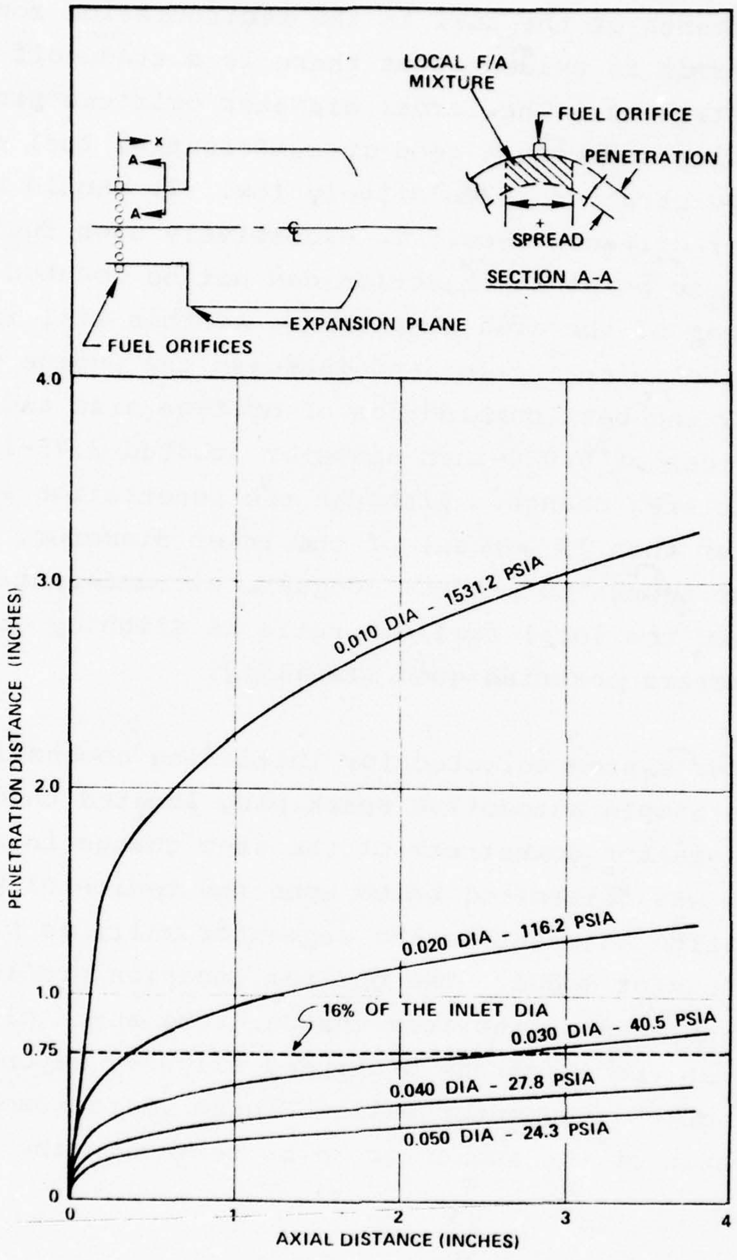


Figure 10. Fuel Orifice Size Effect on Spray Penetration for the ETJ131 (8 Nozzles).

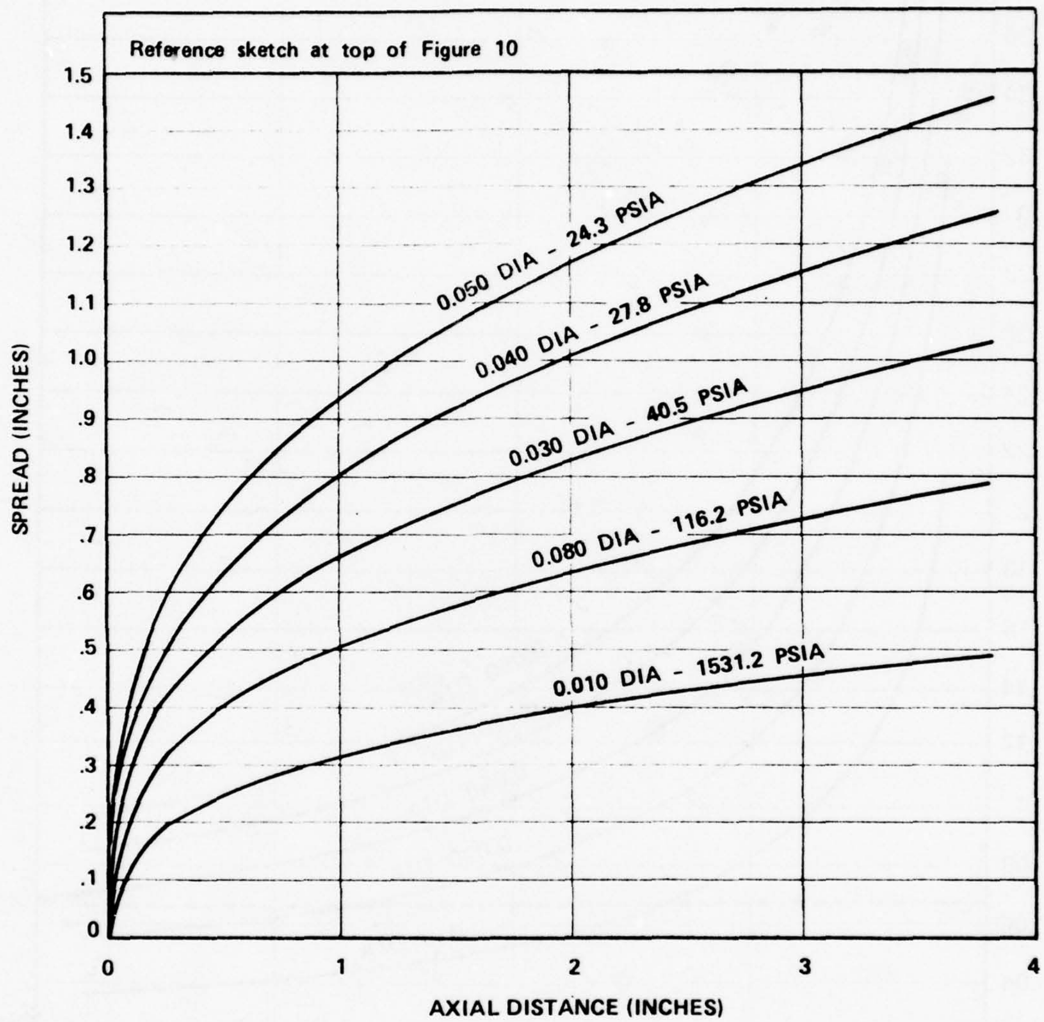


Figure 11. Fuel Orifice Size Effect on Fuel Spread for the ETJ131 (8 Nozzles).

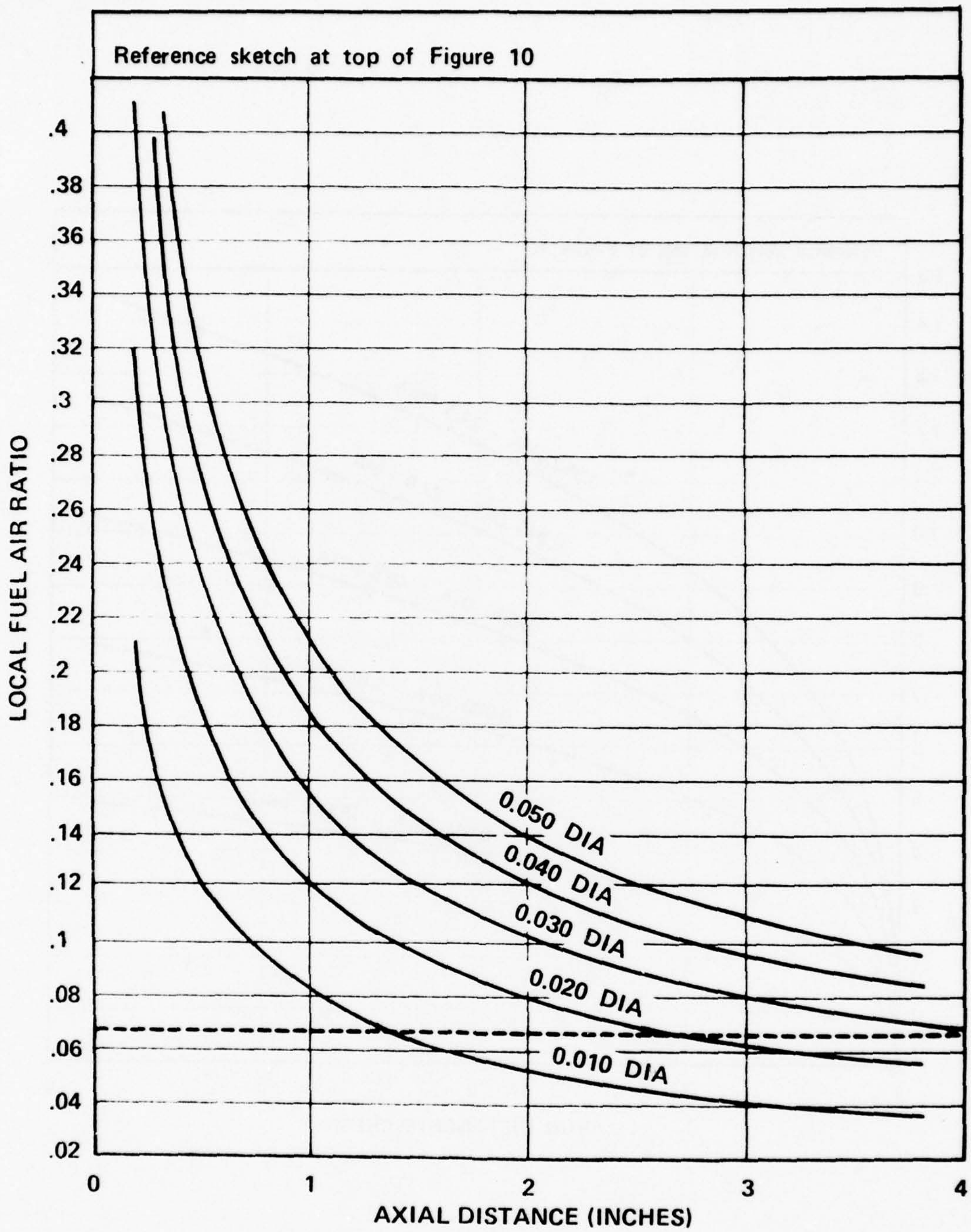


Figure 12. Fuel Orifice Size Effect on Fuel/Air Ratio for the ETJ131 (8 Nozzles).

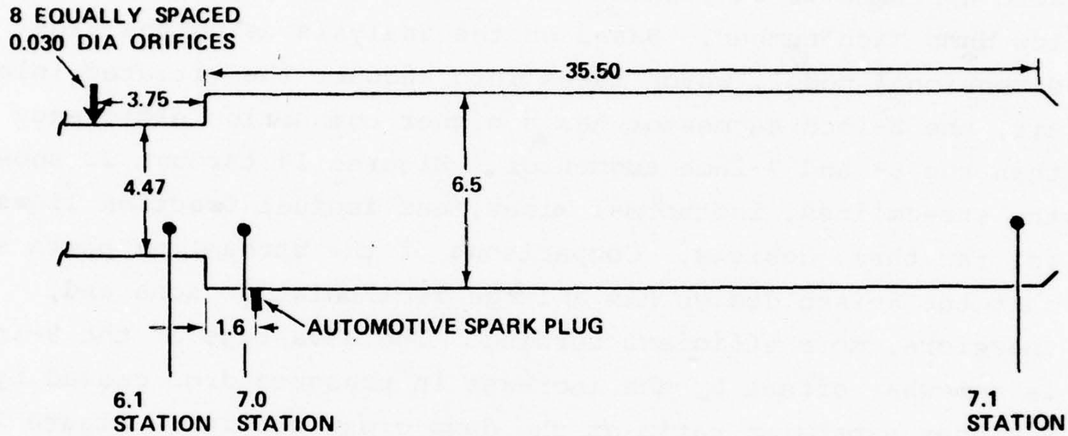


Figure 13. Augmentor (6.5-Inches) for the ETJ131.

(2) Model 1030 Augmentor Design

Three augmentor designs, varying in combustion chamber diameter were examined as candidates for the Model 1030. The three diameters investigated were 6.0, 7.0, and 8.0 inches. Table 5 shows the differences between the three augmentors based on empirically derived parameters. It is evident from Table 5 that the 6-inch augmentor could provide unstable operation due to the high dump Mach number. The 8-inch augmentor also appeared to be marginal in stability due to the relatively low dump Mach number. Based on the analysis using the two-dimensional model, which takes into account the vitiated inlet air, the 8-inch augmentor has a higher combustion efficiency than the 6- and 7-inch augmentor. Figures 14 through 22 show the streamlines, isothermal lines, and isofuel fraction lines for the three designs. Comparisons of the streamline plots show that the 8-inch design has a large recirculation zone and, therefore, more efficient burning. The advantage of the 8-inch is somewhat offset by the increase in pressure drop caused by a higher expansion ratio at the dump cross section. Figure 23 presents the trade-off between augmentor efficiency and pressure drop. Even though the large dump diameter offers a higher combustion efficiency, it also increases the pressure drop, which reduces the thrust. Another impact of the dump diameter is the weight and size of the augmentor. For a fixed-length augmentor, increasing the diameter increases the engine weight and size, which reduces the effective thrust-to-weight ratio. The 7-inch combustor was selected as the best compromise between performance, weight, size, and stability.

The same fuel injector penetration, spread, and local fuel/air ratio analysis was conducted for the Model 1030 as was reported above for the ETJ131. For the Model 1030, both 4 and 8 injectors were evaluated. The results are presented in

TABLE 5. MODEL 1030 PRELIMINARY AUGMENTOR DESIGNS.

Parameter	6 Inch	7 Inch	8 Inch
$D_{6.1}$, Inlet Diameter (inches)	4.7	4.7	4.7
$V_{6.1}$, Inlet Velocity (fps)	859	859	859
D_7, Dump Diameter (inches)	6.0	7.0	8.0
V_7, Dump Velocity (ft/sec)	527	387	296
M_7, Dump Mach Number	0.235	0.173	0.132
Length (inches	29.5	29.5	29.5
L/D_7	4.92	4.21	3.69
$\left(\frac{V_{6.1}}{d_e}\right)\left(\frac{14.7}{P_{t7}}\right)\left(\frac{1000}{T_7}\right)^{1.5}\left(\frac{12}{1000}\right)$	2.65	1.49	1.04
$A_7/A_{6.1}$	1.63	2.218	2.897

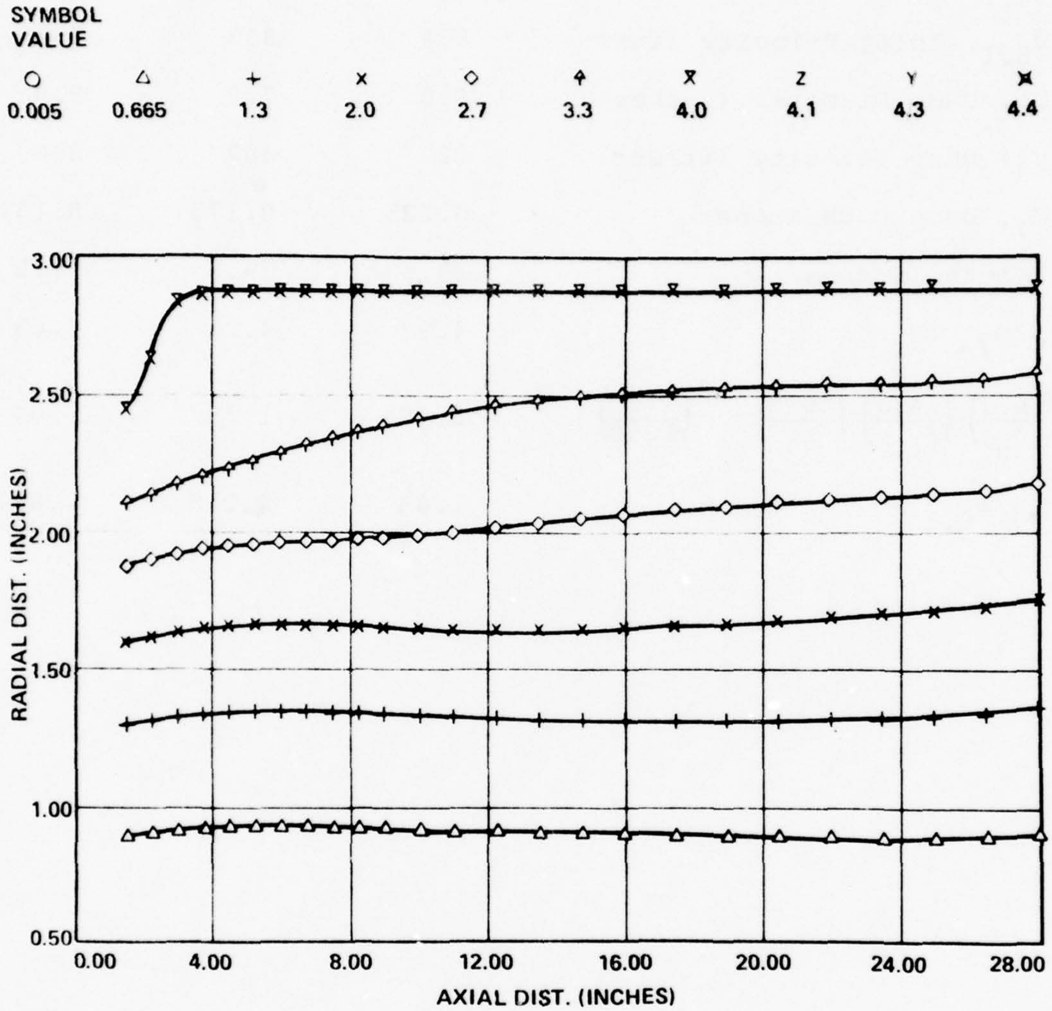


Figure 14. 6-Inch Augmentor for Model 1030
(Streamlines - lbm/sec).

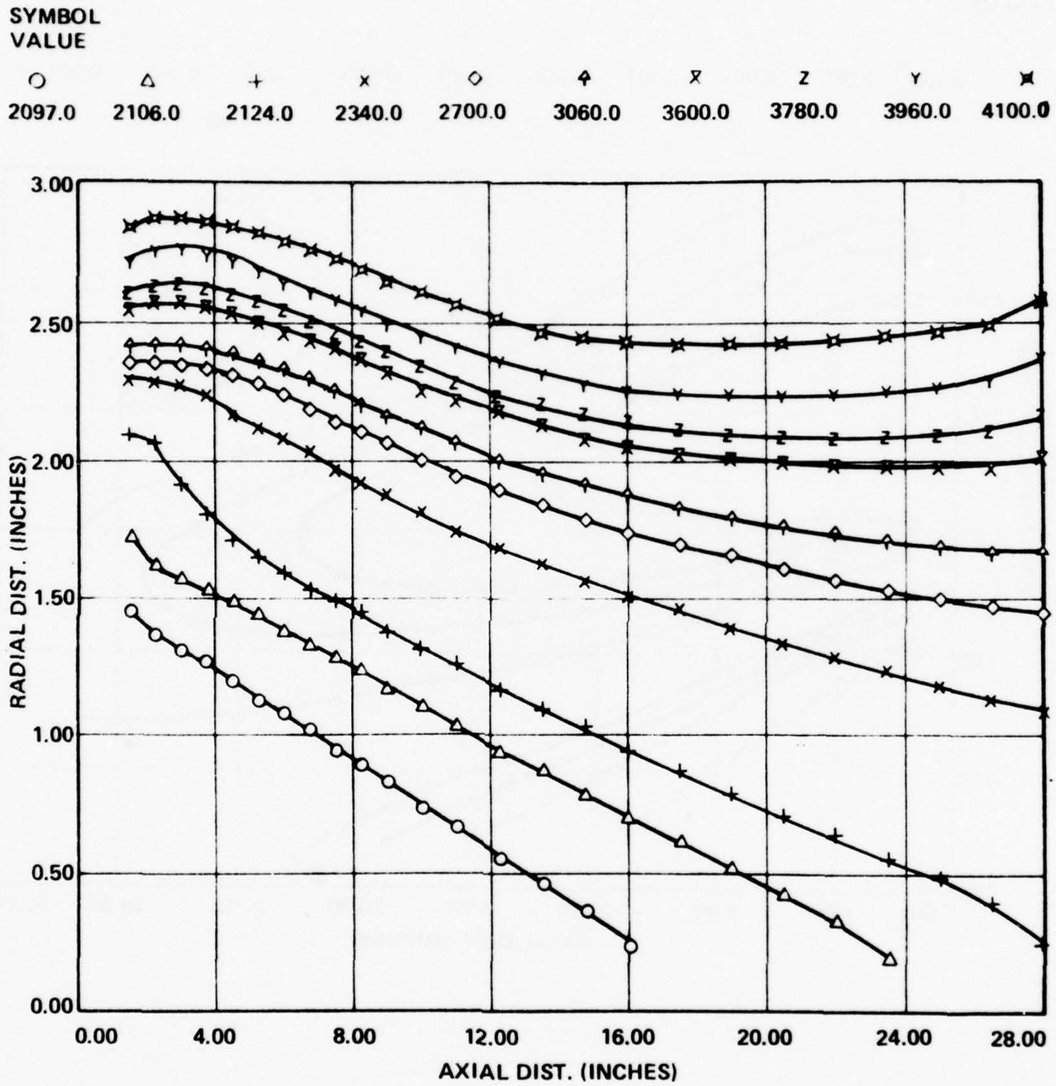


Figure 15. 6-Inch Augmentor for Model 1030 (Isothermal Lines - Deg R).

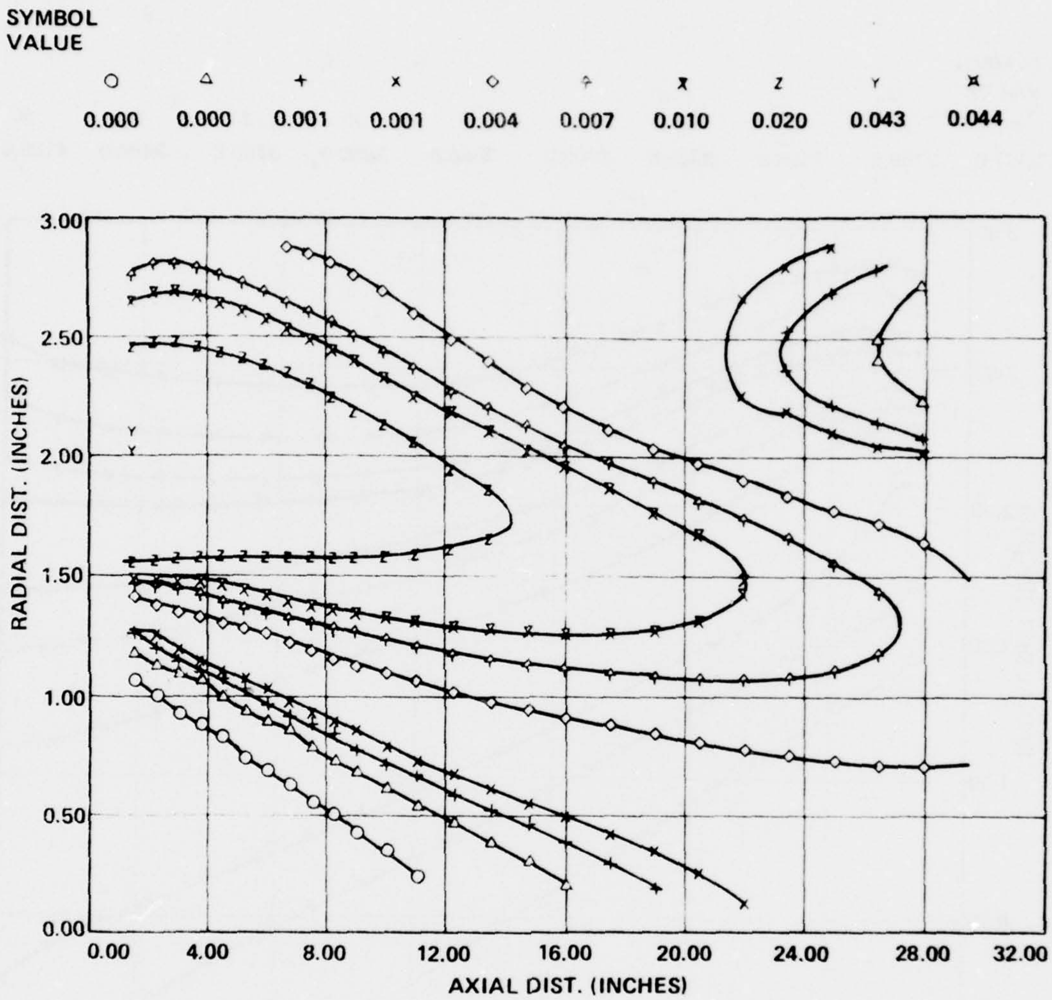


Figure 16. 6-Inch Augmentor for Model 1030
(Isofuel Fraction Lines).

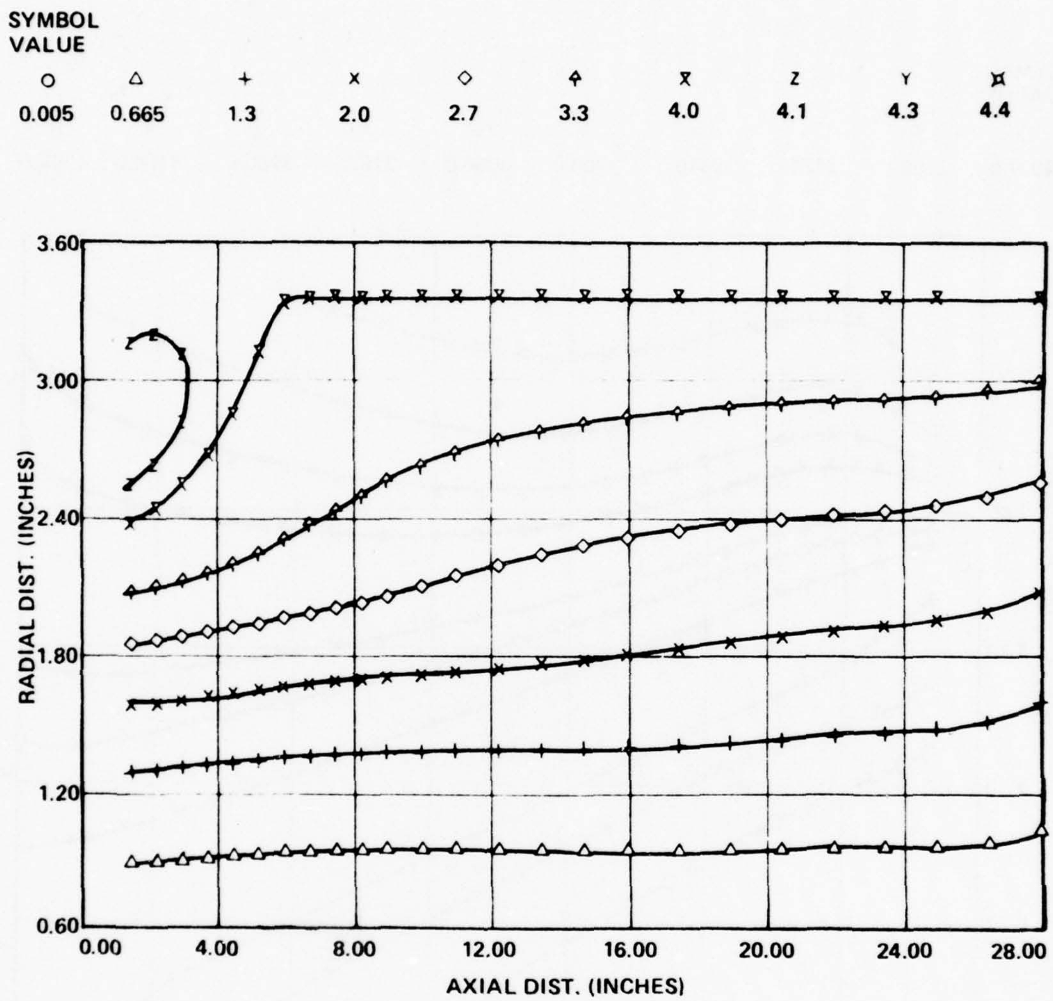


Figure 17. 7-Inch Augmentor for Model 1030 (Streamlines - lbm/sec).

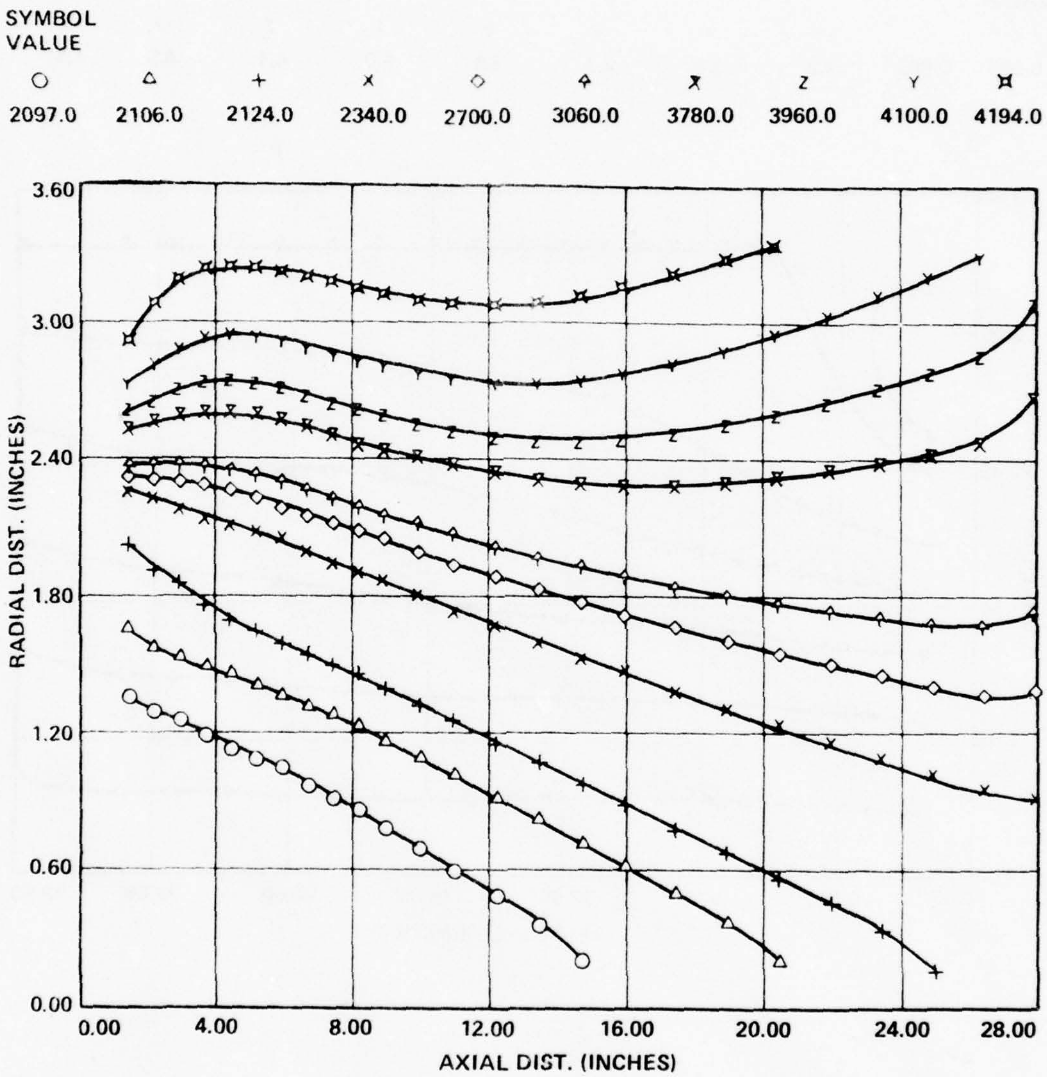


Figure 18. 7-Inch Augmentor for Model 1030
(Isothermal Lines - Deg R).

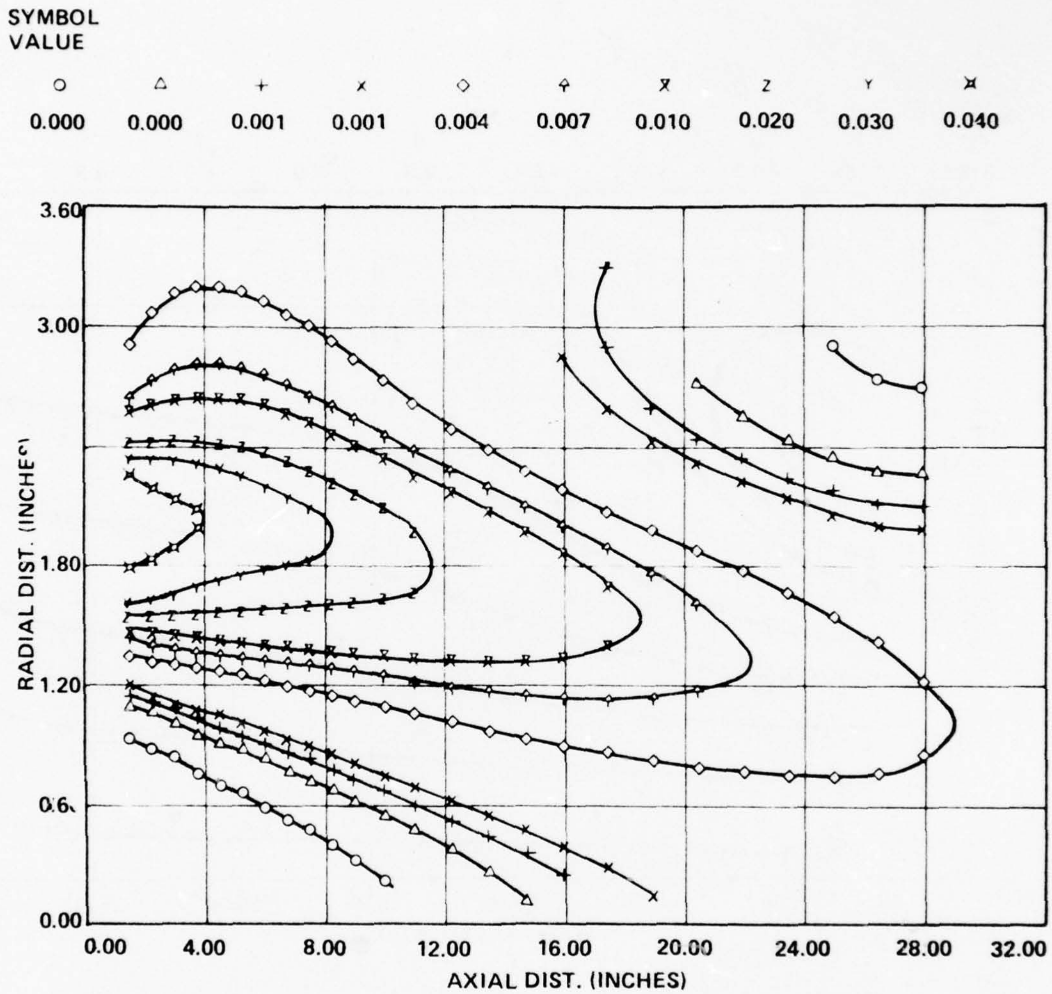


Figure 19. 7-Inch Augmentor for Model 1030
(Isofuel Fraction Lines).

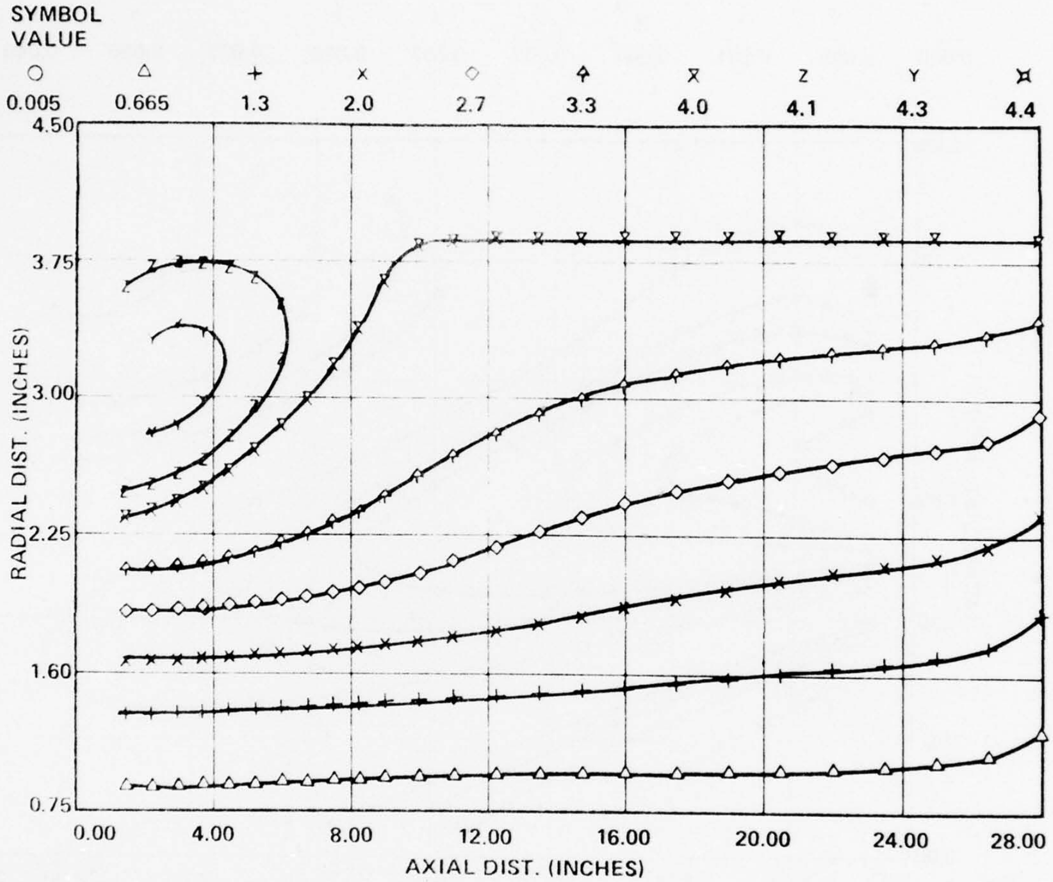


Figure 20. 8-Inch Dump Augmentor for Model 1030 (Streamlines - lbm/sec).

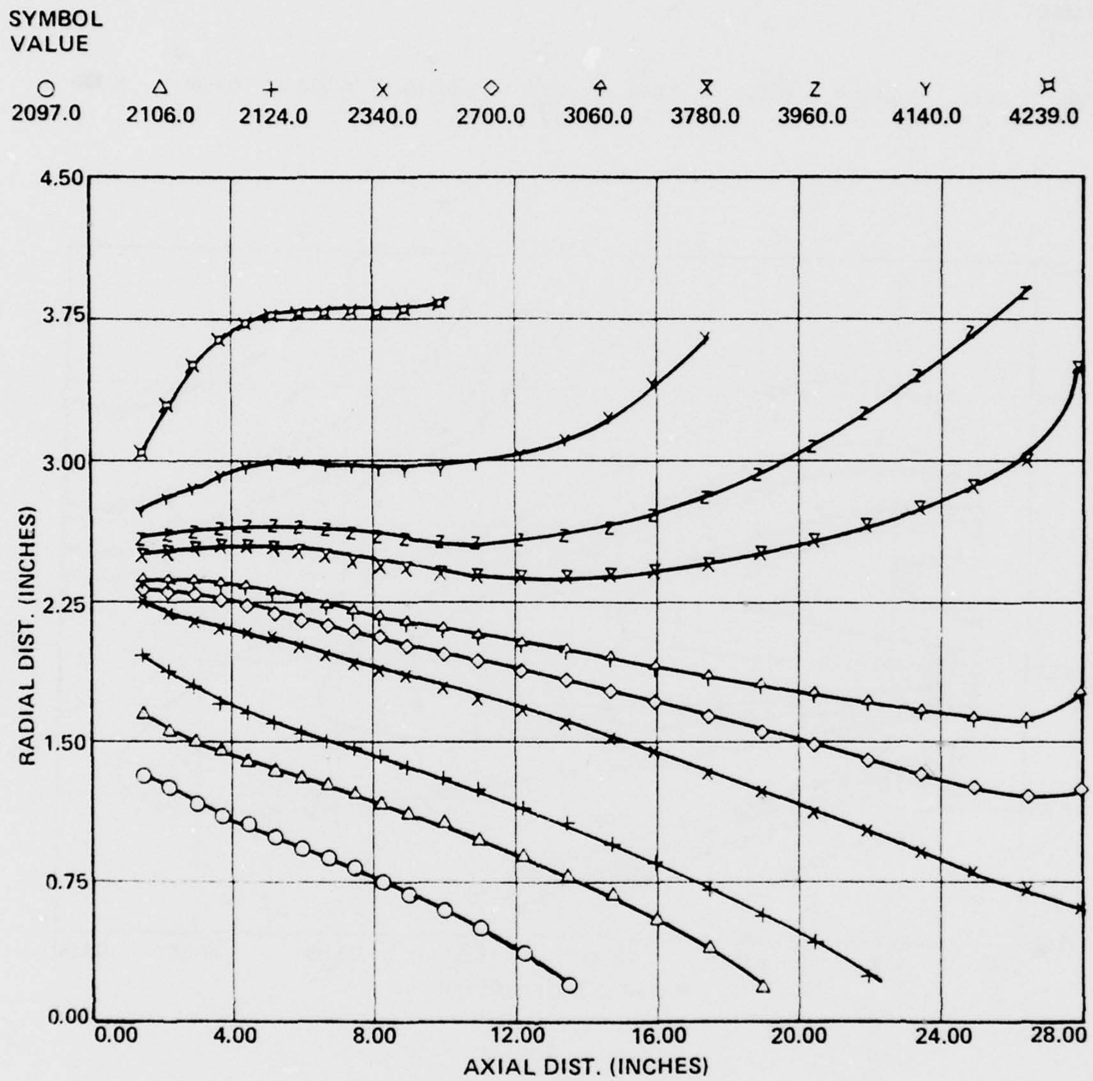


Figure 21. 8-Inch Augmentor for Model 1030 (Isothermal Lines - Deg R).

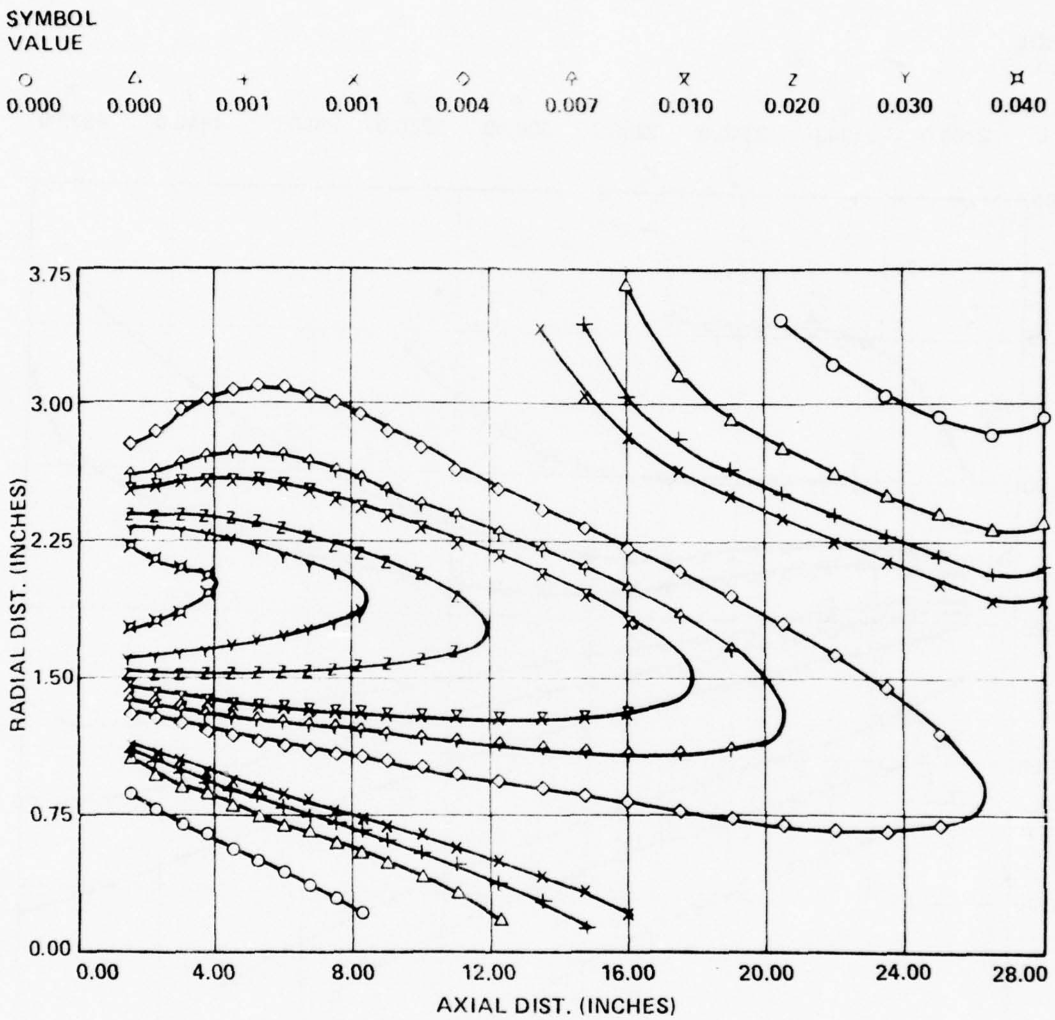


Figure 22. 8-Inch Dump Augmentor for Model 1030 (Isofuel Fraction Lines).

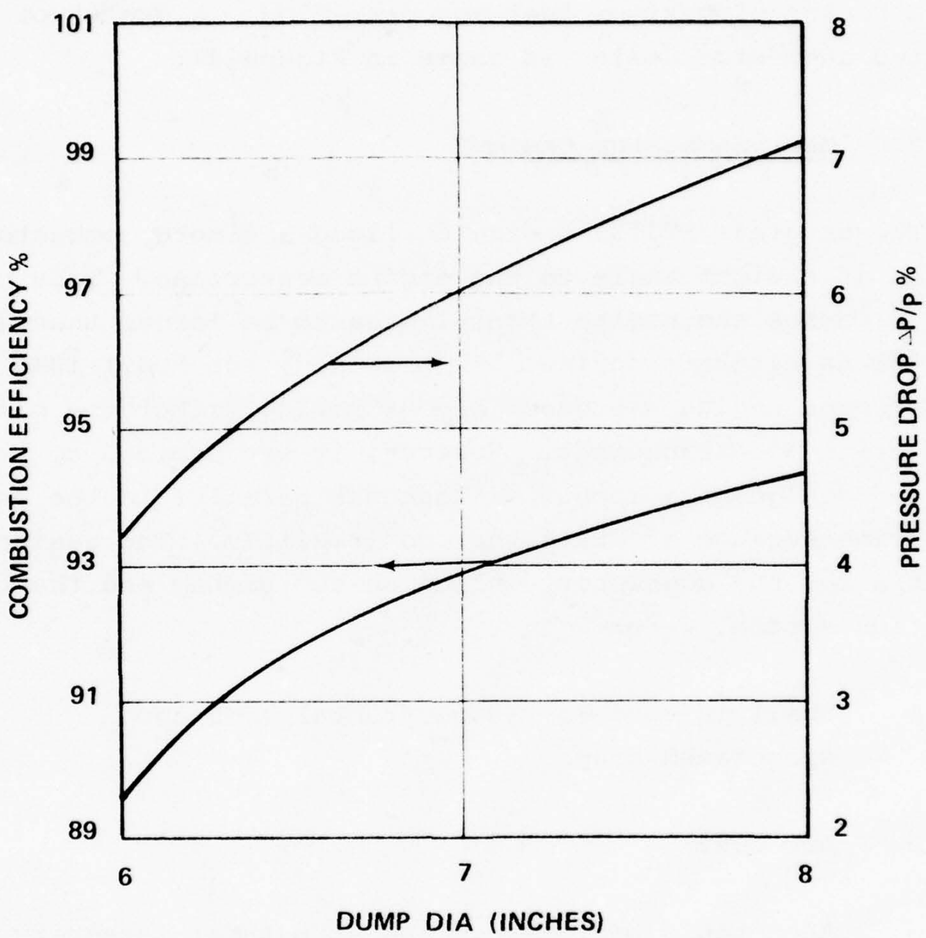


Figure 23. Effect of Dump Diameter on Augmentor Efficiency and Pressure Drop.

Figures 24, 25, and 26. The best selection is eight flush orifices, 0.035 inch in diameter, located 3.6-inches upstream of the sudden expansion.

Ignition was accomplished with a turbine engine ignitor plug located 3.75-inches downstream of the expansion to coincide with a region of maximum fuel concentration. A sketch of the selected augmentor design is shown in Figure 27.

e. Main Combustor Design

The original ETJ131 engine utilized a simple combustor mounted at a right angle to the engine centerline. This configuration causes the engine frontal area to be larger than desirable for an aircraft engine. As proposed, the Model 1030 demonstrator engine was described as having either the parallel or right-angle arrangement. However, it was decided to proceed with the design of a combustor that was parallel to the engine centerline because of its higher desirability. The design criteria for the combustor, including the plenum and the fuel injection system, were:

- Small in size to reduce frontal area and associated drag
- Low cost
- Acceptable performance and structural integrity for the length of the mission.

The design methods employed were based on empirical relations for general can combustor design, and also included information derived from the design and testing of the ETJ131 combustor. A comparison of the operating conditions for the combustors for both the ETJ131 and the Model 1030 are presented in Table 6.

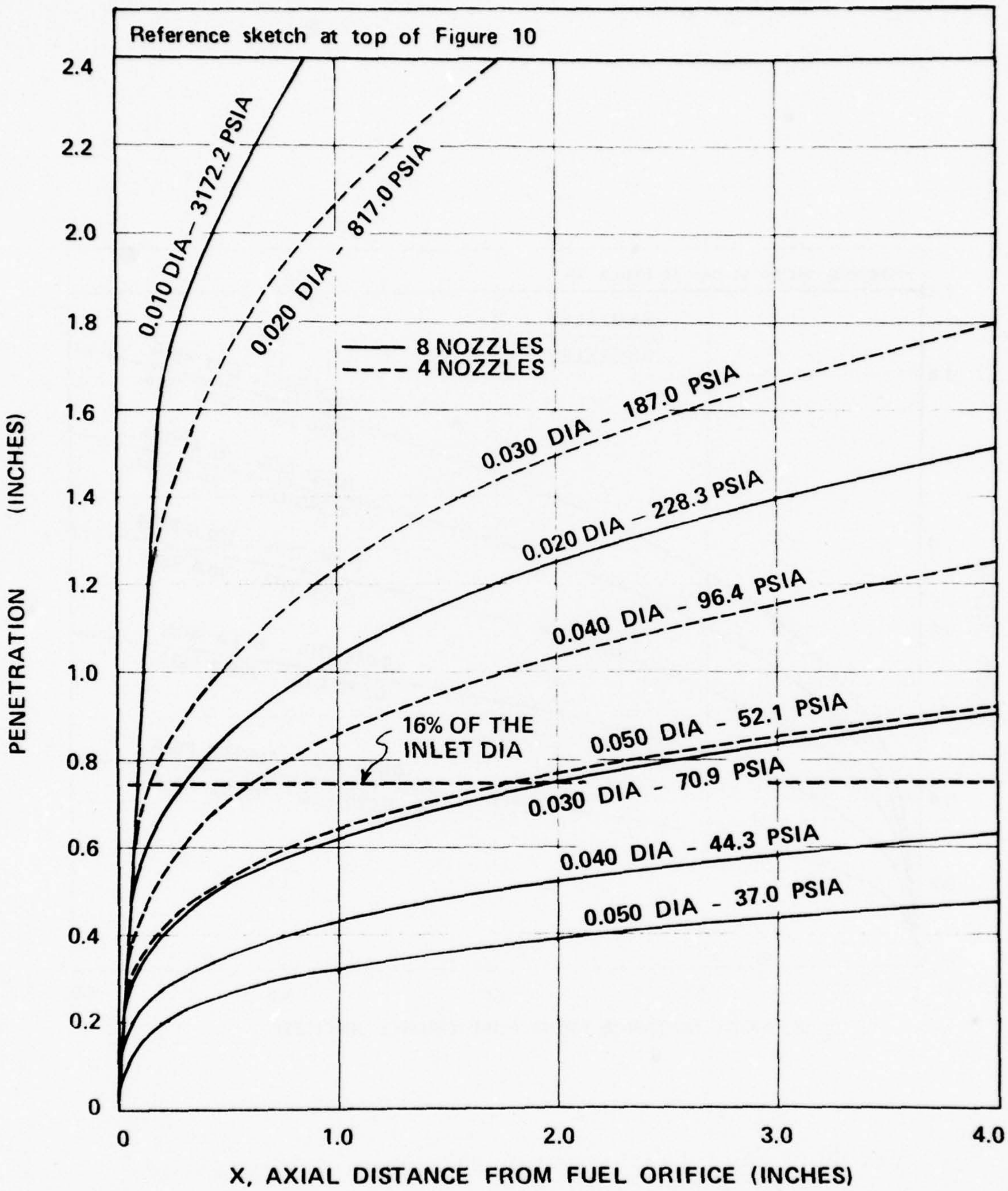


Figure 24. Fuel Orifice Size Effect on Spray Penetration for the Model 1030.

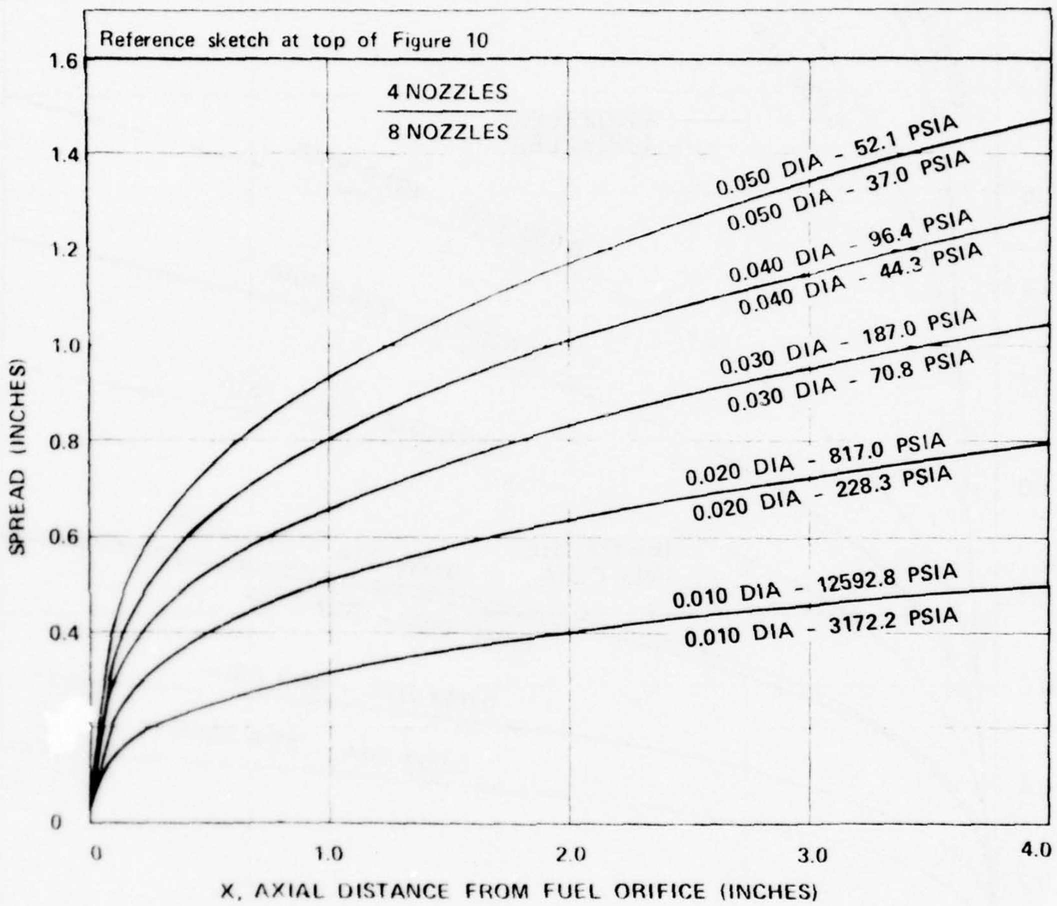


Figure 25. Fuel Orifice Size Effect on Spray Spread for the Model 1030.

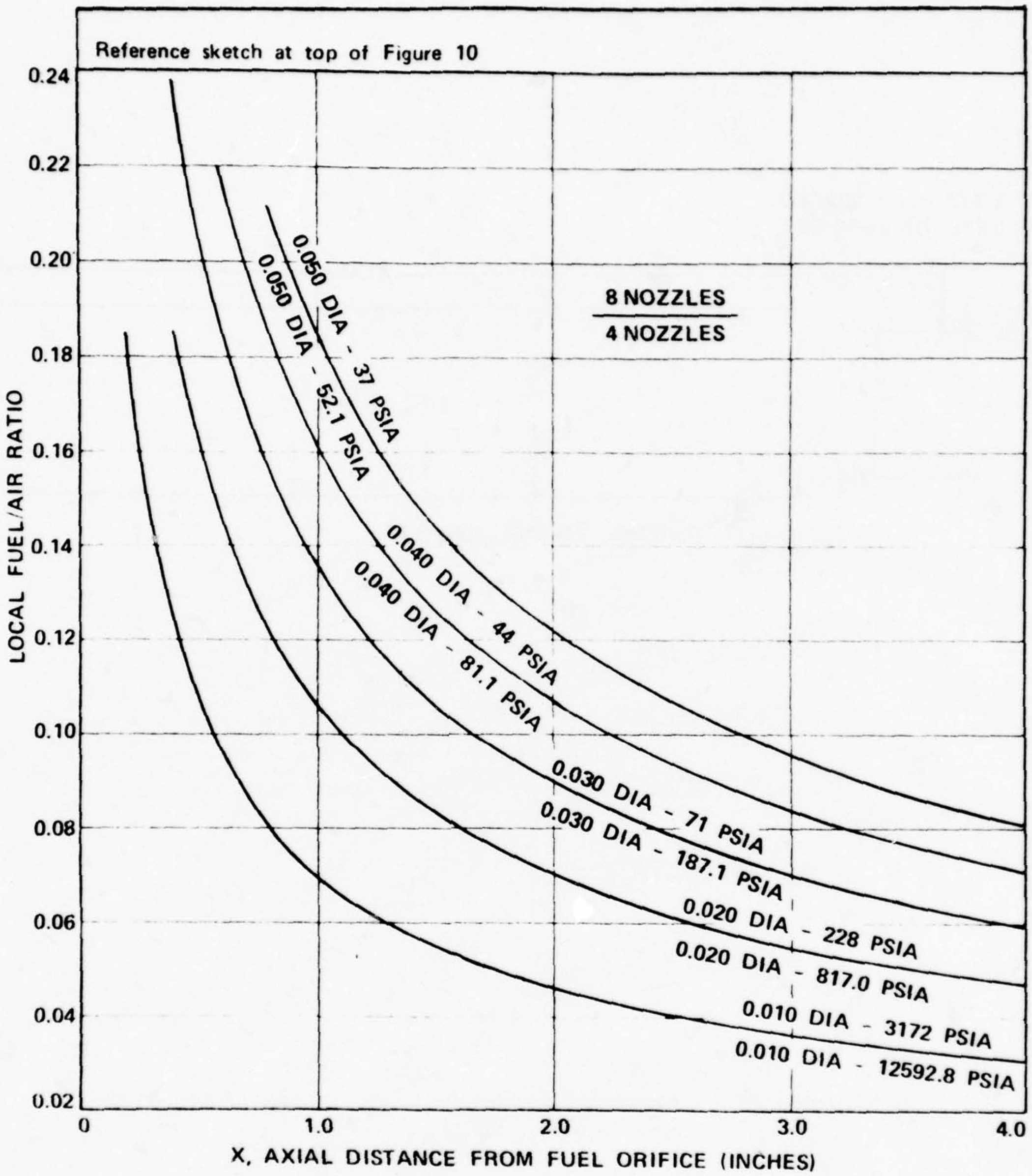


Figure 26. Fuel Orifice Size Effect on Local Fuel/Air Ratio for the Model 1030.

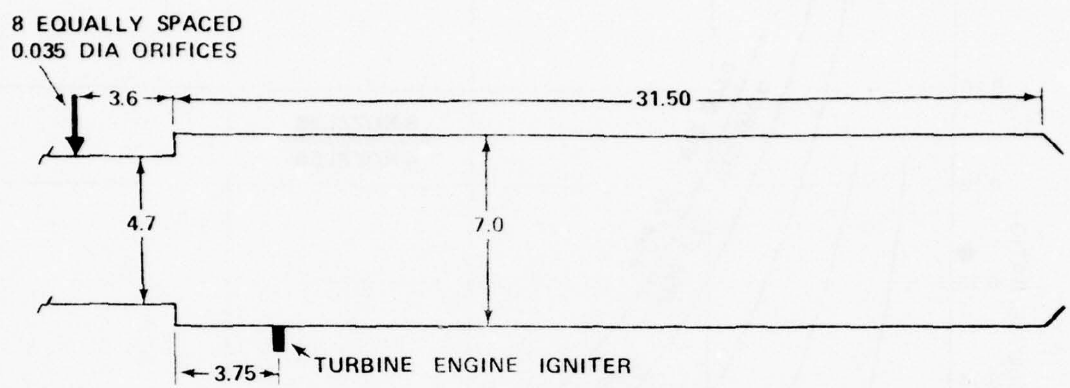


Figure 27. Augmentor (7.0-Inch Diameter) for the Model 1030.

TABLE 6. COMPARISON OF THE ETJ131 AND THE MODEL 1030 PRIMARY COMBUSTOR INLET CONDITIONS (SEA-LEVEL, STATIC CONDITIONS).

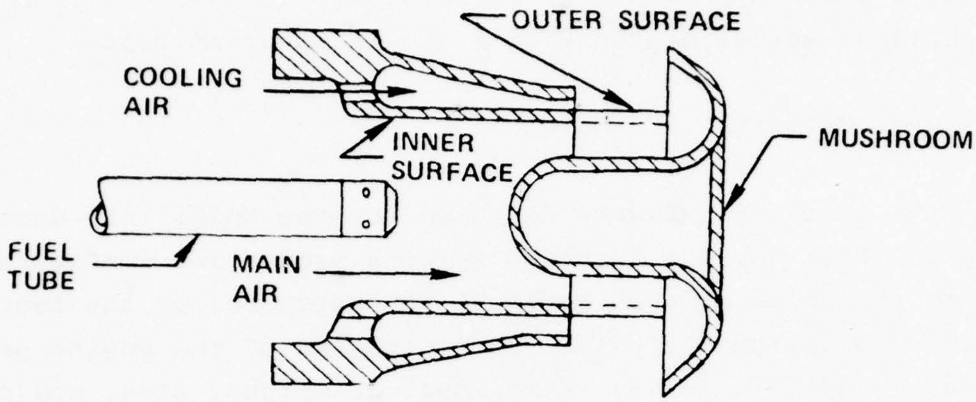
Parameter	ETJ131	Model 1030
T_{t3}, Inlet Temperature (°F)	368	371
P_{t3}, Inlet Pressure (psia)	47.9	50.8
W_a, Air Flow Rate (pps)	2.27	2.84
$W_a\sqrt{\theta_3}/\delta_3$, Corrected Airflow (pps)	0.88	1.04
W_f, Fuel Flow (pph)	168.5	244.1
T_{t4}, Discharge Temperature (°F)	1700	1900

(1) Fuel-Insertion Devices

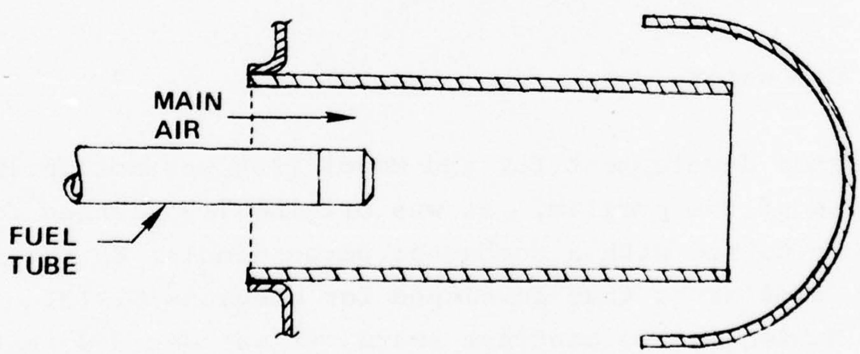
Cost was a major consideration in selecting the fuel injection device for the Model 1030 Engine. In order to minimize the cost of the fuel injector and the associated control equipment, the fuel injector was limited to a low-fuel-pressure device utilizing either a vaporizer or an airblast fuel injector. Indications from the compressor performance estimates showed that at the engine light-off speed, there would be only 1 to 2 inches of water-pressure drop across the combustor. Since state-of-the-art airblast atomizers require 5 to 8 inches of water pressure drop to achieve good atomization, the airblast system was ruled out.

The design variations considered for the injector are shown in Figure 28. Design A is more complex than Design B, but should have a longer life and more uniform fuel distribution in the circumferential direction. With poor fuel distribution, a hot streak could exist and cause localized melting of the transition liner.

The mushroom vaporizer (Design A) introduced air through two different locations. The fuel that is sprayed on the inner wall by the fuel tube, is carried around the vaporizer by the main air. The flow rates are selected to produce a high equivalence ratio, specifically 7.55. This ratio is rich enough to ensure that the cap will not melt. Additional cooling air is introduced in a manner to cool the outer wall and to impact the fuel leaving the mushroom to aid in the atomization of the fuel that is not vaporized. The cooling air is introduced such that after it mixes with the main air and fuel from the vaporizer, an overall equivalence ratio of 4.0 exists.



MUSHROOM VAPORIZER
DESIGN A



MUSHROOM VAPORIZER
DESIGN B

Figure 28. Design Variations A and B of the Mushroom Vaporizer for the Model 1030 Engine.

Design B is a simplified version of Design A and offers attractive cost savings. The fuel is sprayed on the cup by the fuel tube to provide cooling that is carried around by the main air flow in the same manner as Design A. This design was selected as a first approach since it was similar to the system used in earlier testing of the ETJ131 and is lower in cost.

2. PRODUCTION ENGINE DESIGN

The specific hardware designed for the Model 1030 demonstration test was not intended to be a production configuration. Due to the scope of this program, the hardware for the test engine was designed to allow demonstration of the engine performance and life goals. Attainment of weight, size, and cost goals were to be based on a production engine design. Specific components affected by this approach included:

- Combustor
- Turbine scroll
- Augmentor and thrust nozzle
- Bearing and lubrication system
- Fuel control

a. Combustor

Combustor development for the Model 1030 was not included in the scope of the program. It was origincally planned for the engine to be tested with a combustor perpendicular to the engine centerline similar to that developed for previous ETJ131 engines. Subsequent to contract award, it was decided that there was sufficient confidence in a combustor design having its axis oriented parallel to the engine centerline to warrant a demonstration attempt with this design. Accordingly, the basis for a production weight, size, and cost estimate of this component was available.

b. Turbine Scroll

The test engine was to be designed with a new turbine scroll not presently in production. This was necessitated by the increased flow and operating temperature of the Model 1030. A secondary goal was to achieve a lighter weight by changing the material from GMR235 -- as used in most production turbochargers -- to a higher temperature material, and to reduce the average wall thickness of the scroll.

This secondary goal was to be achieved without changing the fabrication method presently used in turbocharger production or launching a casting development program. The material of the new test engine turbine scroll was changed to Hastelloy-X, and the average wall thickness was reduced from 0.5 inch to 0.375 inch. Further thickness reductions were determined to be risky without the benefit of significant casting development effort. A significant weight reduction was not achieved even though the wall thickness was reduced as it was offset by the size increase of the scroll.

Other approaches for reducing the weight of the scroll include:

- Sheet metal fabrication
- Chemical milling
- Investment casting

Sheet metal fabrication is considered the most promising and a limited amount of work has been accomplished to verify feasibility. However, engine cost would undoubtedly increase. The extent of this cost increase was not determined. However, it is believed that the investment cast approach would be more expensive than the sheet metal approach for reasonable yields.

The weight of the Hastelloy-X turbine housing, as fabricated for the demonstration engine, is 45.6 pounds. If a sheet metal or investment cast approach were developed, weight of the turbine housing is estimated at approximately 21 pounds. This corresponds to an average wall thickness of 0.15 to 0.20 inch.

c. Augmentor

The augmentor, as tested, is similar to that envisioned for a production design. The major changes would consist of optimizing the material thickness of the metal case and, as pointed out by demonstration testing, improving the method of retaining the ablative liner.

The weight of the augmentor as tested was 35.5 pounds. The estimated weight of a production version is 29 pounds. The reduction in weight is due to reducing the thickness of the metal case from 0.062 to 0.040 inch. The weight breakdown of a production augmentor is:

o	Metal case	- 13.2 pounds
o	Ablative liner	- 13.7 pounds
o	Ignitor, fuel nozzles	- 2.0 pounds
	Total	28.9 pounds

The thrust nozzle designed for the test engine is shown in Figure 29. A sketch giving dimensions is shown in Figure 30. The length of the nozzle is approximately 11 inches due to the chosen nozzle half angle of 7 degrees. This length, and therefore the weight, could be reduced in half by increasing the half angle to 15 degrees. There is a tradeoff between a weight decrease (2.0 pounds maximum) and nozzle performance change that was not investigated. The weight of the test nozzle is 4.5 pounds.

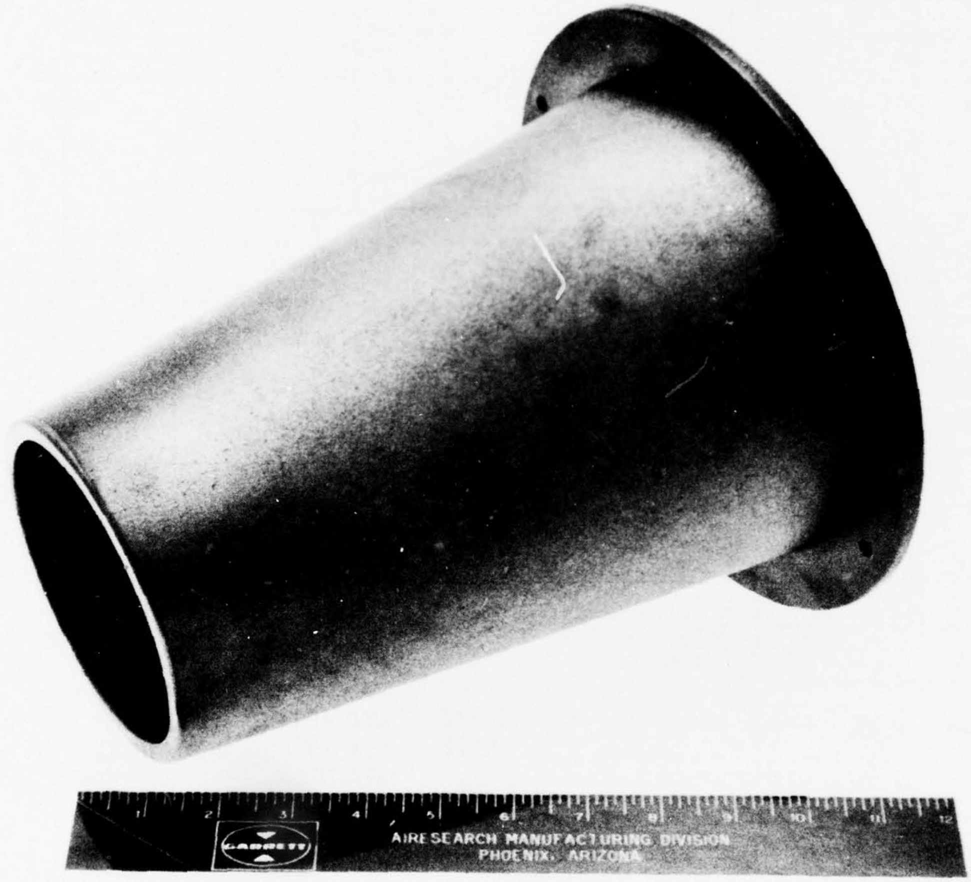


Figure 29. Thrust Nozzle.

MP-61289

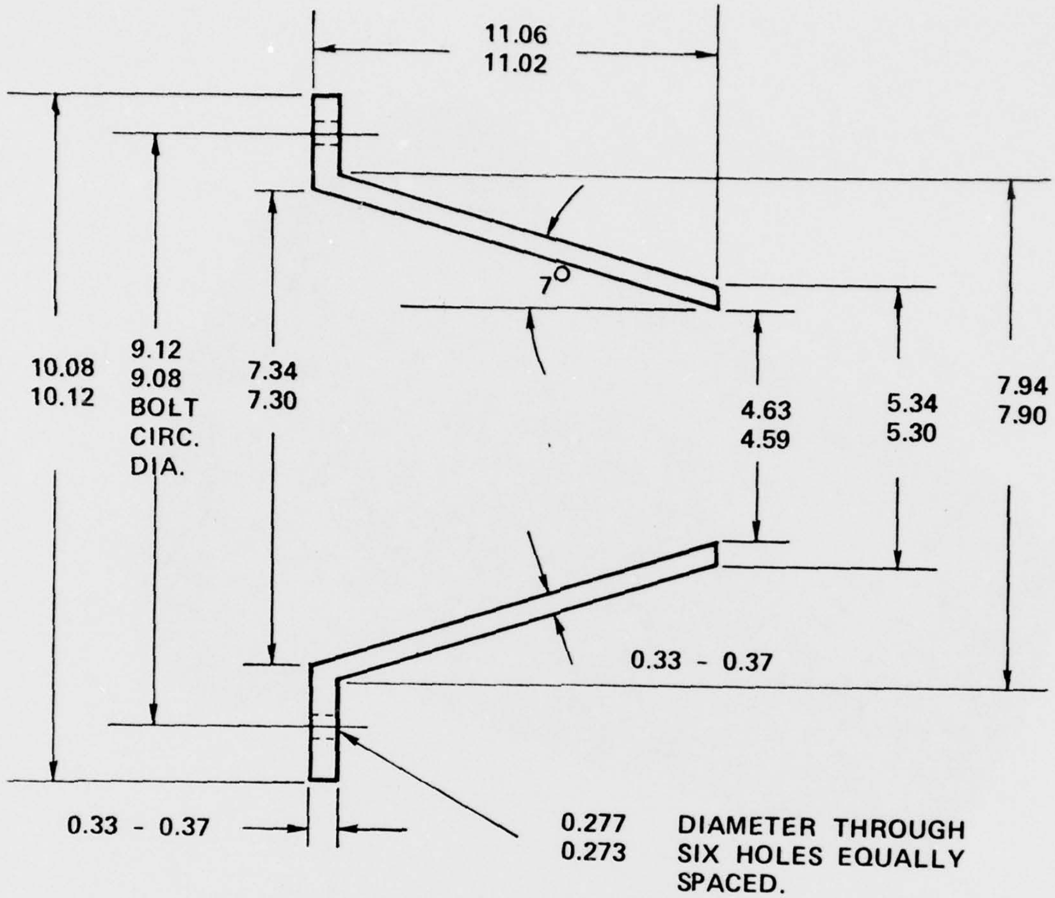


Figure 30. Thrust Nozzle Outline.

d. Bearings and Lubrication System

There were no provisions for bearing or lubrication system study or development in this program. The system selected for test is the standard sleeve bearing with external lubrication system. In a related program, (Contract F33615-76-C-2072) sleeve bearings with an engine-mounted, self contained lubrication system, and a ball bearing air/oil mist system was investigated. For projecting cost and weight of a production engine, the ball bearing air/oil mist system was selected.

e. Fuel Control

There were no provisions for fuel control study or development in this program. The basis for the cost and weight of a fuel control were based on conceptual design study conducted under USAF Contract F33615-76-C-2072 of a fluidic control system. The estimated weight of this control, as applied to the Model 1030, is 1.5 pounds.

f. Production Engine Design

A cross section of the production engine design is shown in Figure 31. The production cost and weight estimates are based on this drawing with one significant difference. To allow for installation of the ablative liner, the material is tapered from a thickness of 0.375 inch at the forward end to 0.313 at the aft end of the augmentor.

The calculated frontal area of the production engine is 181 square inches or 1.26 square feet. This compares to the goal of 1.2 square feet. The estimated volume of the engine is 2.5 cubic feet, as compared to the goal of 3.0 cubic feet.

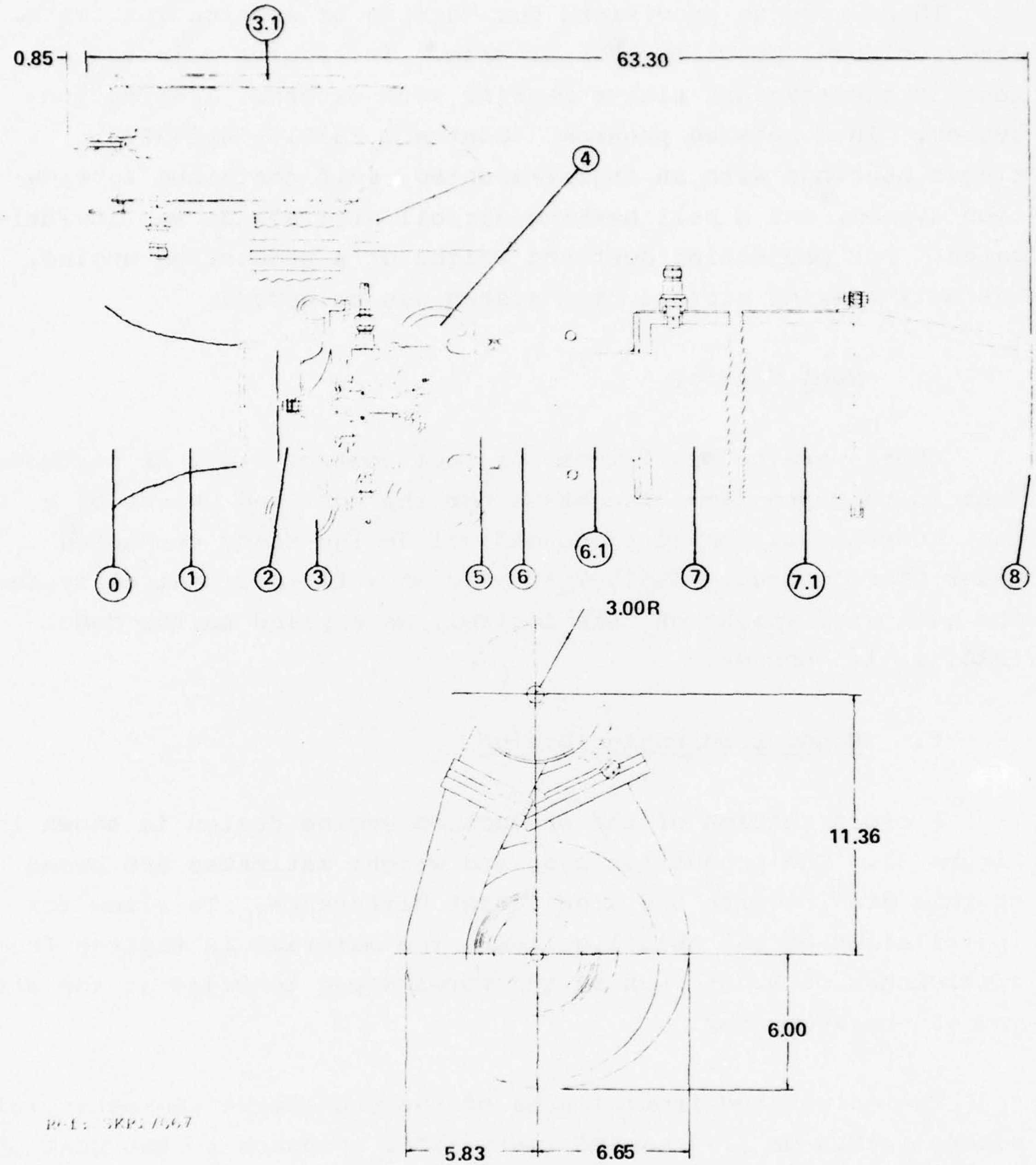


Figure 31. Production Engine Cross Section.

g. Production Engine Weight Estimate

The estimated weight breakdown of a production version of the ETJ131 Model 1030 engine is shown in Table 7.

TABLE 7. ESTIMATED ENGINE WEIGHT BREAKDOWN ETJ131 MODEL 1030-PRODUCTION VERSION.

Component	Baseline Engine Weight (Pounds)	Estimated Production Engine Weight (Pounds)
Turbocharger center housing and rotating group	18.0	18.0
Compressor housing	5.1	5.1
Turbine housing	14.4	21.0
Combustor	12.5	14.2
Fuel control and pumps	1.5	1.5
Augmentor	29.0	28.9
Nozzle	3.0	4.5
Miscellaneous	3.0	3.0
TOTAL	86.5	96.2

The estimated weight, although less than the program goal of 100 pounds, can be improved with further development. Primary areas for weight reduction include the combustor ($\sim$2 pounds), the nozzle ($\sim$1 to 2 pounds), and the augmentor ($\sim$4 to 5 pounds).

Of the elements included in the production weight estimate, the center housing and rotating group, compressor housing, combustor and nozzle are actual weights. The augmentor and fuel control weights are based on actual weights. The turbine housing weight is the only element of the estimated engine weight that is not based on actual hardware.

h. Production Cost

The production engine cost estimate was based on the cross-section drawing shown in Figure 31. The estimate is in 1977 dollars and based on a yearly production rate of 1000 units/year. The estimate shown in Table 8 is believed to be accurate to ±30 percent as specified in the contract.

TABLE 8. ETJ131 MODEL 1030 PRODUCTION ENGINE COST ESTIMATE 1977 DOLLARS, 1000 UNITS PER YEAR.

Components	Costs (Dollars)
Turbocharger	700
Fuel control and pumps	340
Combustor assembly	355
Augmentor and nozzle	875
Plumbing	45
Assembly	220
Production test	265
TOTAL	2800

The cost estimate in Table 8 was prepared before the fabrication of the new, larger turbine nozzle was completed and before the demonstration test. Casting difficulties with the high temperature material turbine housing indicates that a sheet metal or investment cast approach will be required. Although some increase in cost for the turbine housing was allowed, relative to current turbocharger housings, it is not sufficient to cover the cost of a sheet metal or investment cast approach. Also, the demonstration tests showed the need for a more sophisticated and more expensive ablative liner retention system. Accordingly, the price, as shown, can be expected to increase.

3. FABRICATION AND PROCUREMENT - TASK IC

The main engine components fabricated during the program were:

- o Combustor
- o Turbine housing
- o Augmentor
  - Water cooled version for basic ETJ131
  - Model 1030 version with ablative lining
- o Exhaust nozzle

a. Combustor

As previously discussed, it was decided early in the program to demonstrate the engine with the parallel combustor rather than the perpendicular combustor originally planned. From a fabrication standpoint, many of the combustor parts are common to either design; the primary difference being the transition elbow from the liner exit to the turbine inlet. Two sets of combustor parts were fabricated, but only one set was assembled. The second set was held in reserve in case it was necessary to revert to the proven perpendicular combustor design. The combustor design is a welded assembly made from 321 stainless steel. The outline drawing is shown in Figure 32 and the finished part is shown in Figure 33.

Several changes from the design described in subsection 1 were made to simplify construction and reduce cost. Major changes included the elimination of the dome hats, alteration of the combustor hole pattern, and substitution of version B of the mushroom vaporizer fuel nozzle. The dome hats were removed

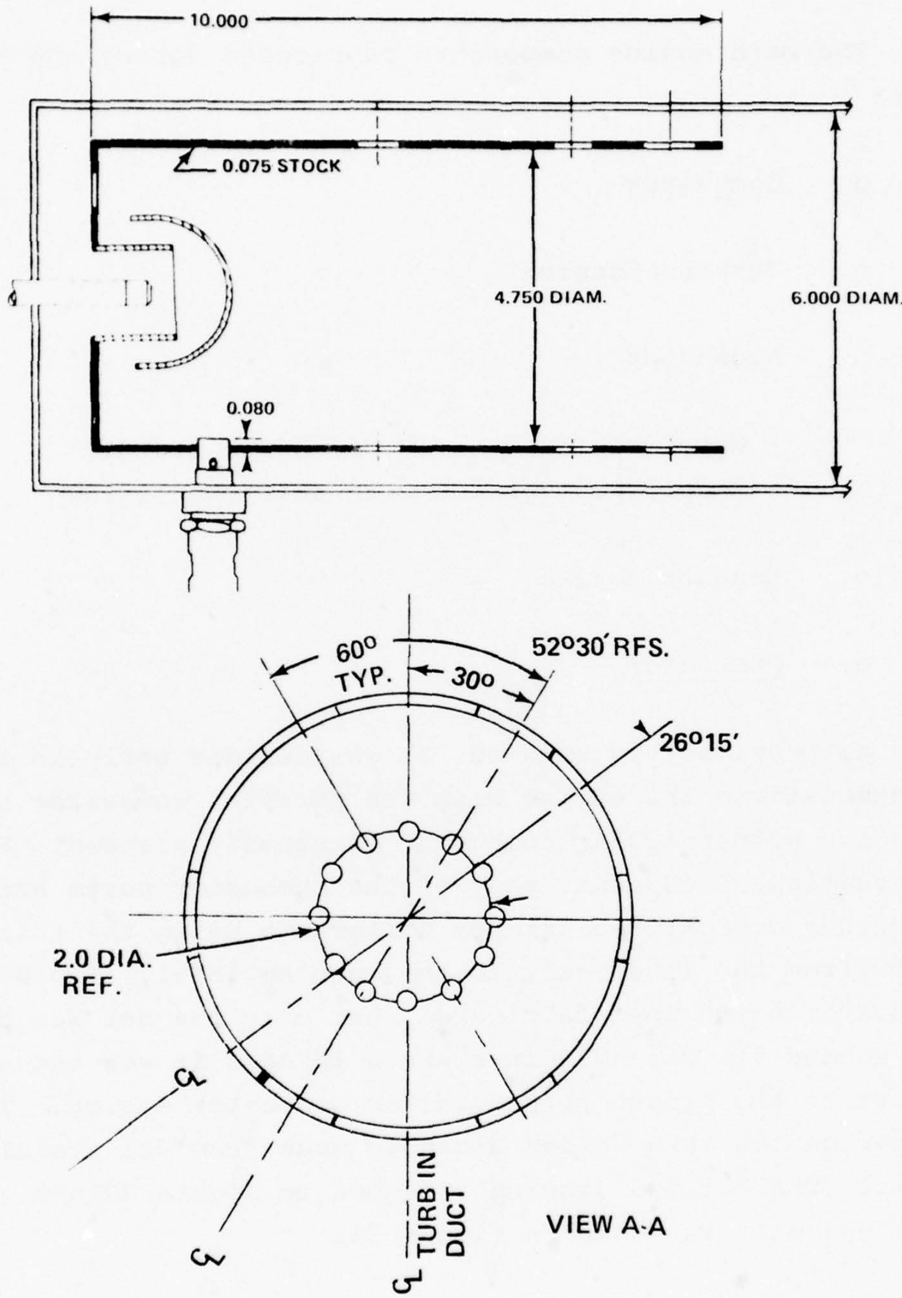


Figure 32. Outline Drawing.

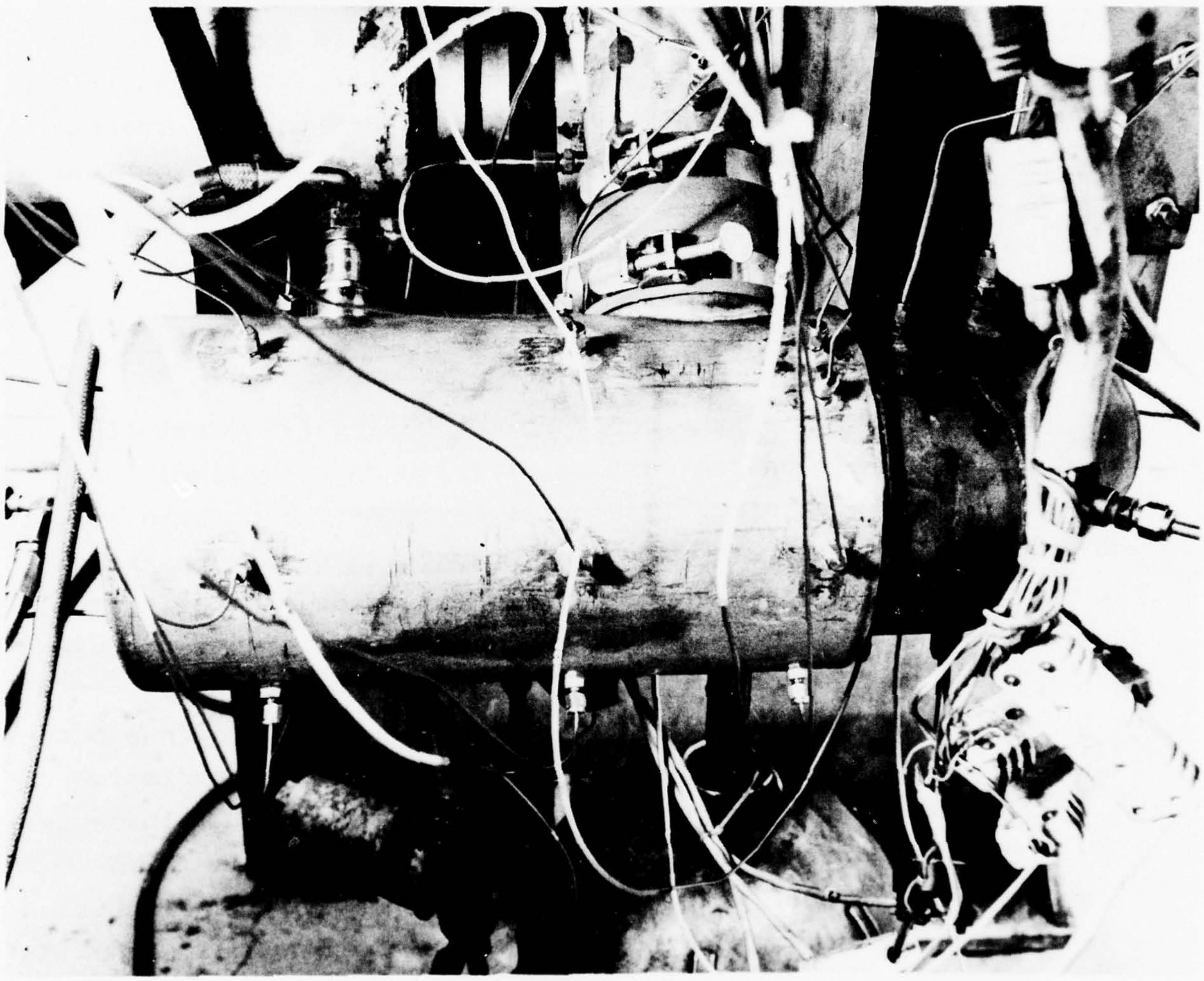


Figure 33. Combustor Before Modification.

because they were costly to fabricate and weld onto the combustor. The dome hats were replaced by 12 holes equally spaced on the combustor dome concentric about the vaporizer centerline and 12 holes equally spaced on the combustor wall approximately 3/4-inch downstream of the dome. The original design of the plenum and combustor specified internal diameters of 6.0 inches and 4.75 inches, respectivley, fabricated from 0.075-inch stock. Neither of these dimensions resulted in standard pipe or tubing sizes; therefore, the plenum and combustor were fabricated from 6.024 O.D. by 0.066 wall and 5.00 O.D. by 0.063 tubing, respectively. Slight changes in the combustor orifice dimensions were also made to reflect earlier experience in the original ETJ131 combustor design.

b. Turbine Housing

The fabrication of the new turbine housing from Hastelloy was done by the AiResearch Casting Division to specifications prepared by the AiResearch Industrial Division. The turbocharger was a direct scale of a Model T-18A production turbine housing. Fabrication included the design and construction of casting tooling, casting of the turbine housing, and machining. The turbine housing is sand cast which is normal for the low quantity required. Shell mold castings are normally used for high production quantities. The surface finish and other characteristics of sand castings are essentially identical with shell mold castings. However, once tooling is developed, shell molds (high-temperature fused sand with binder) can be prepared in quantities for high production. Whereas, sand casting molds require considerably greater preparation time per piece.

Three attempts were required to cast acceptable housings, although the problems were typical of those encountered in casting a new part particularly with a new material, such as Hastelloy. The primary problems were shrinkage, core slip, and porosity. The last attempt produced castings that had some porosity and shrinkage cracks but were weld repairable. For a production program, the casting problem encountered could definitely be solved and castings can be produced that would not require weld repair.

Three acceptable turbine housings were made and two were sent out for weld repair.

c. Augmentor Fabrication

Two versions of augmentors were fabricated during the program. The first was a water-cooled version, sized for the basic ETJ131 engine. It was of all metal construction including a water-cooled metal nozzle. The second version was the demonstration unit and consisted of a metal case with a Dow Corning 93-104 ablative liner.

A photograph of the water-cooled design is shown in Figure 34. Two cooling circuits are provided. The first cools the dump combustor, and the second cools the thrust nozzle. The cooling jacket consists of an 8.0-inch O.D. stainless steel pipe with 0.120-inch wall and two end rings. The cooling jacket slips over the dump combustor, and is supported by two rings welded to the augmentor tube. An O-ring seal is provided between the standoffs and the cooling jacket end rings.

Water is introduced longitudinally at the forward standoff through eight 0.375-inch ports. There are four 0.75-inch water outlets just forward of the cooling jacket end ring. Also included on the augmentor/cooling jacket are two hangers for suspending the assembly on the thrust stand, and an ignitor boss and shield. The ignitor boss is on the cooling jacket and holds the ignitor in place. A shield is provided to protect the ignitor from the water flow.

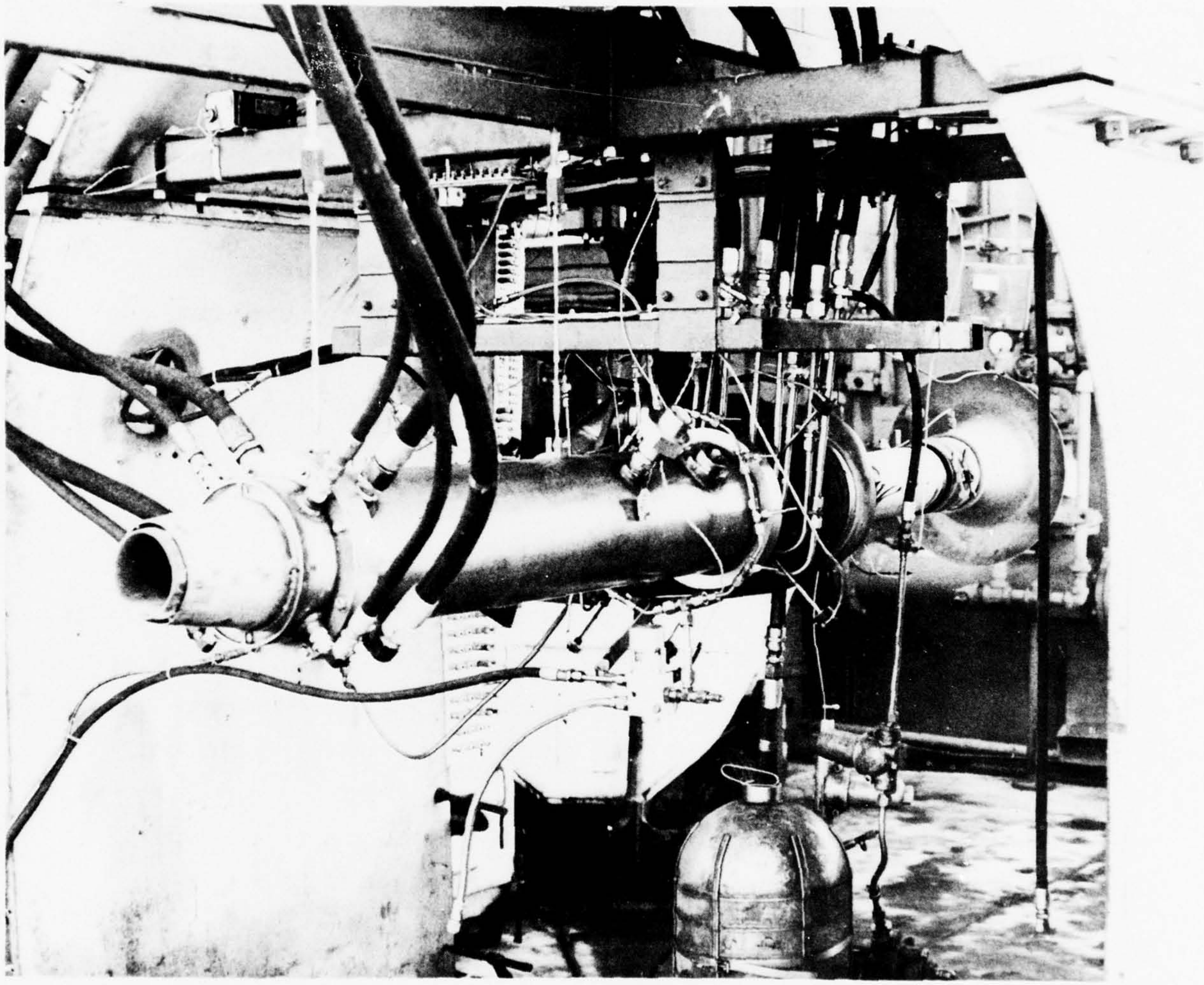


Figure 34. Water-Cooled Augmentor.

MP-58622

Water is introduced behind the aft end ring through four 0.5-inch ports to cool the nozzle. Nozzle cooling flow exits to atmosphere.

The augmentor tube is constructed from 6.5-inch I.D. stainless steel tubing.

The Model 1030 augmentor was fabricated as designed. The metal case was rolled and welded from 0.065-inch wall of 347 stainless sheet. The metal case, as fabricated, is shown in Figure 35. Following fabrication of the metal case, the Dow Corning 93-104 ablative liner was installed. A mandril sized to allow for the desired thickness of the ablative material was fabricated. The thickness of the ablative liner varied from 0.375-inch in the forward section to 0.313-inch at the aft end. The procedure used in applying the liner was:

- Cover the inlet to the combustion section of the augmentor
- Fill the combustion section with the required amount of Dow Corning 93-104
- De-aerate the 93-104
- Plunge a tapered mandril along a guide rod into the 93-104 material from the nozzle end and extrude the material to the proper thickness as set by the mandril dimensions
- Drill holes through the ablative liner at the inlet end to help ventilate gas pockets formed by backside heating

Figures 36 and 37 show the augmentor after installation of the ablative liner.

Figure 35. Model 1030 Augmentor.

Figure 36. Dump Combustor.

MP-60880

Figure 37. Ablative Lining.

MP-60879

d. Thrust Nozzle

The thrust nozzle, Figure 38, was machined from HLN85 graphite by Amercom Corporation. After machining, a silicon carbide coating, 15 mils thick, was applied.

4. ASSEMBLY AND DEVELOPMENT TEST

a. Augmentor Development Testing

Early in the program, it was decided that due to the lead time required for the new turbine housing, it would be beneficial to design and test an augmentor for the smaller, basic ETJ131 to demonstrate feasibility of the concept. This engine does not have the high flow of the Model 1030 and is not designed for the 1900°F turbine inlet temperature of the Model 1030 but a test engine from a previous program was available. A water-cooled design was chosen on the basis of augmentor life and cost.

1. Assembly and Test

The tests were conducted at sea-level, static conditions. The thrust stand and engine installation are shown in Figures 39 through 41. Figure 39 shows the test stand, inlet bellmouth, and primary combustor. Figure 40 shows the turbocharger portion of the engine and the piping that provides high pressure air for starting. Figure 41 shows the water cooled augmentor, the eight water inlet lines, the four water outlet lines, the ignitor boss, and a 1-inch diameter burst disk for system protection.

The augmentor configuration tested had an L/D of 5.5. The water cooling jacket for the exhaust nozzle was easily removed and allowed for cutback of the nozzle to larger areas according to test requirements. The nozzle cooling water discharged as a cylinder of water surrounding the augmentor exhaust gas stream.

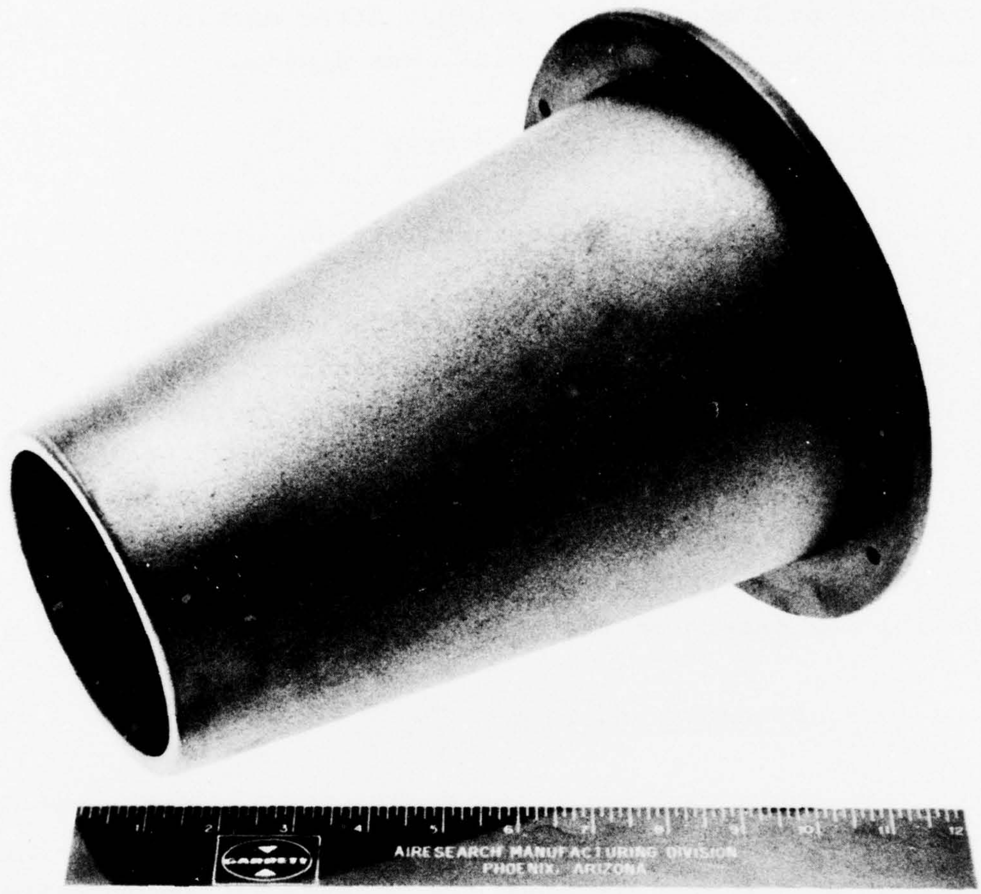


Figure 38. ETJ131, Model 1030 Thrust Nozzle.

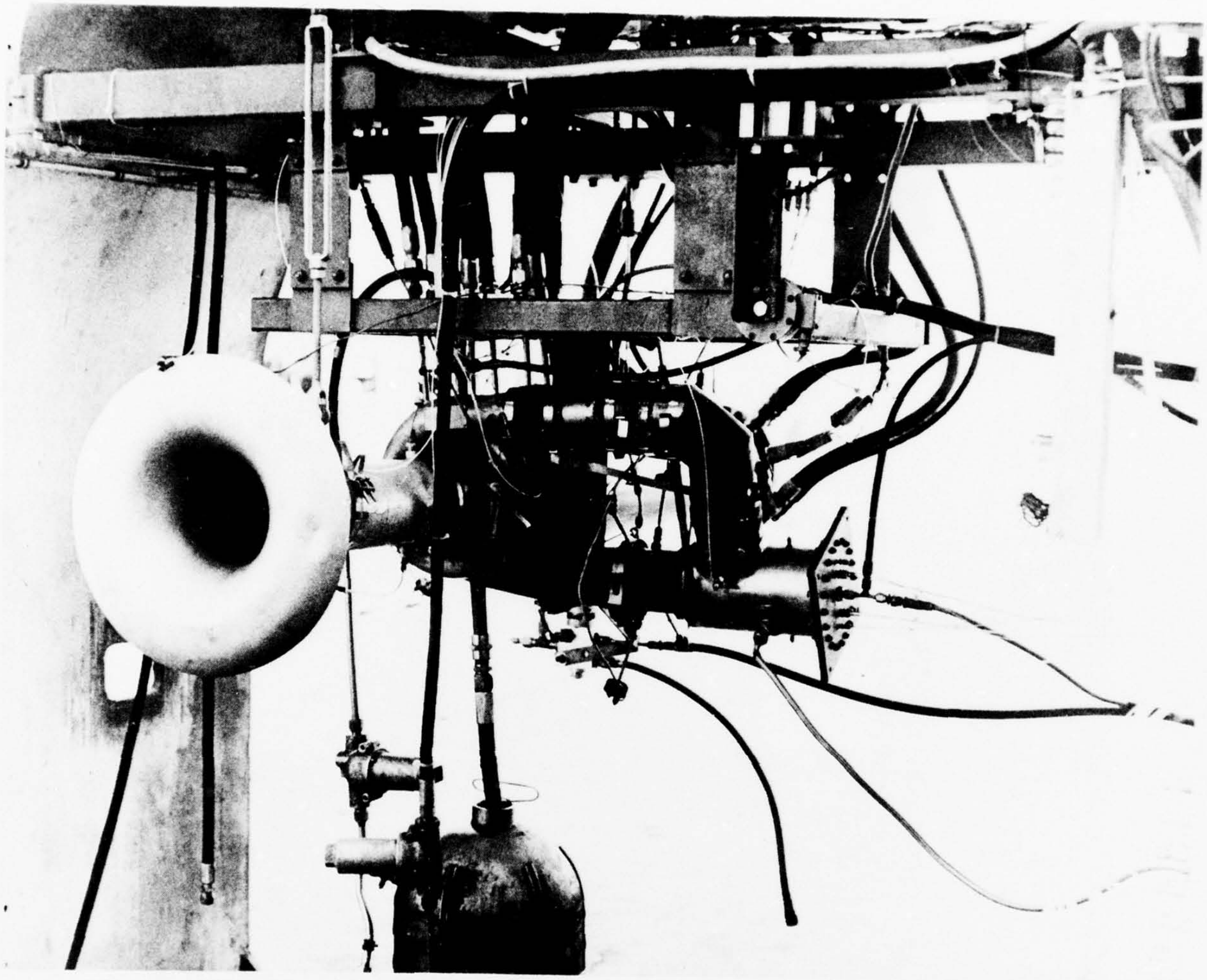


Figure 39. Augmented ETJ131 Test Rig Setup.

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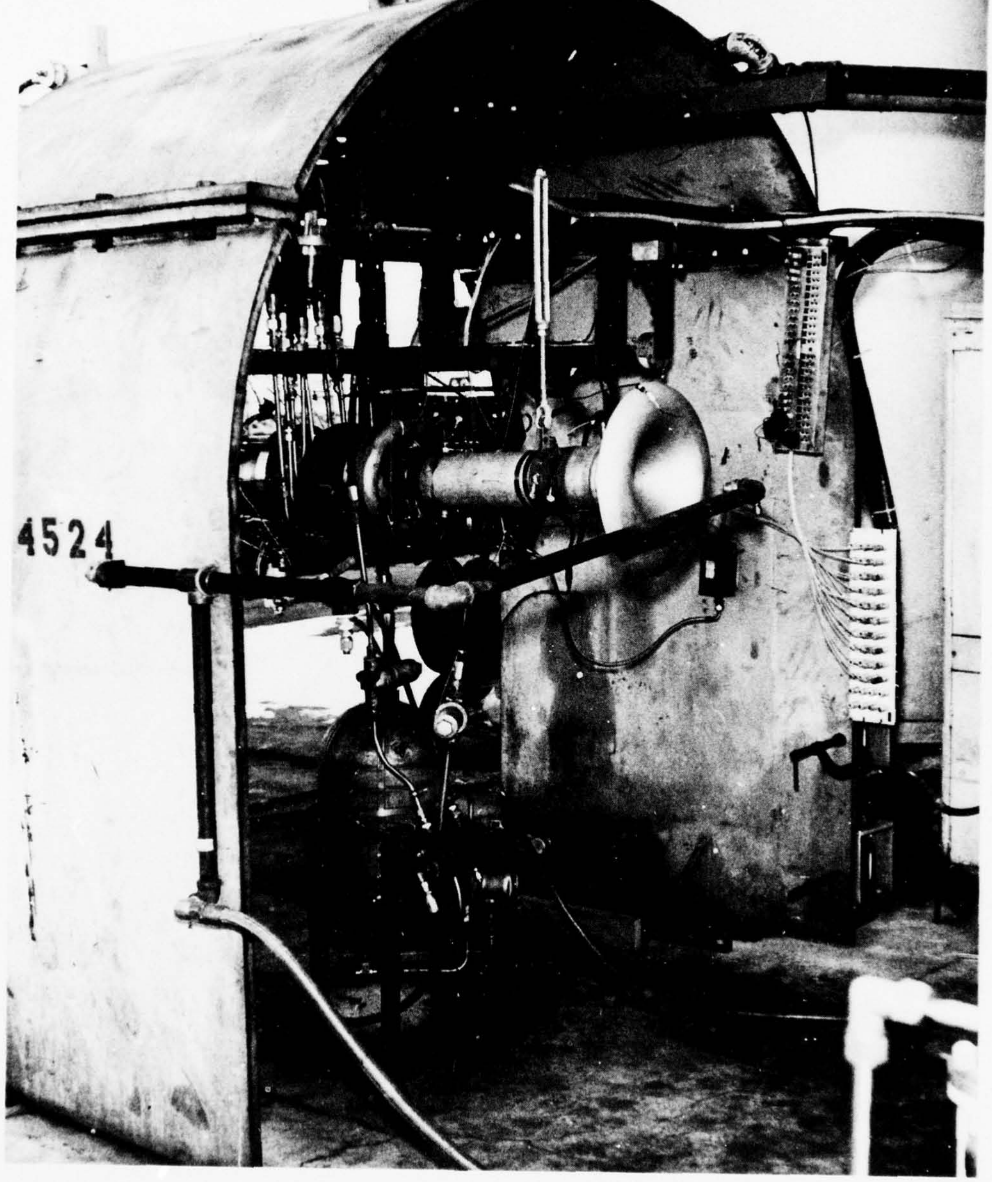

Figure 40. Starting System for Augmented ETJ131
Test Rig Setup.

MP-58621

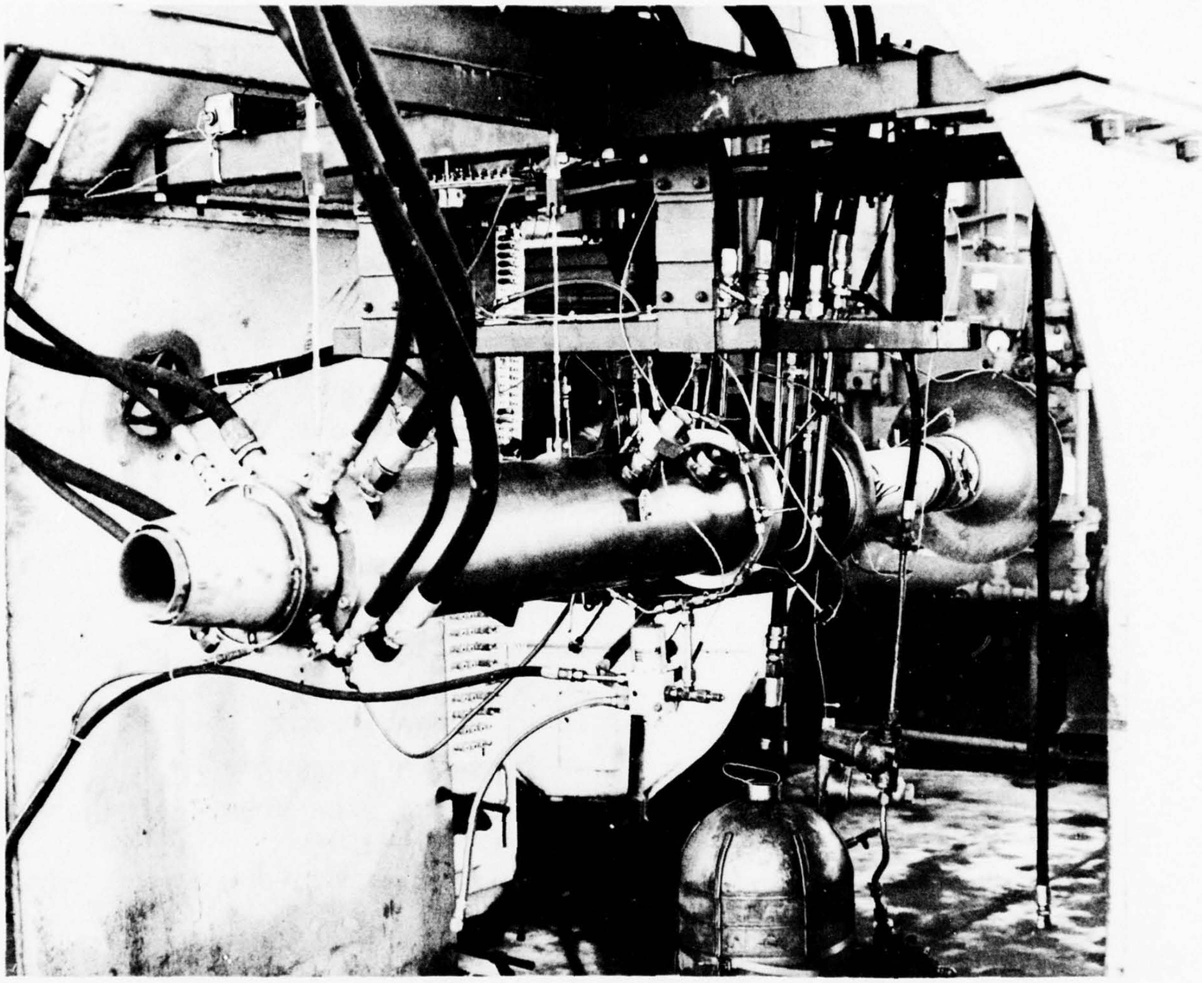

Figure 41. Water-Cooled Sudden-Expansion Augmentor in ETJ131 Test Rig Setup.

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In order to calibrate the augmentor exhaust nozzle and to determine the sudden-expansion burner pressure drop, a special exit total-pressure rake was fabricated. The water-cooled total-pressure rake, adapted from a previous design, consisted of four total-pressure probes constructed from stainless steel with a stainless-steel water jacket. The installation is shown in Figure 42. The water-cooled rake has a thermocouple imbedded in the case to monitor case metal temperature.

2. Instrumentation

Figure 43 defines the engine station designation for the tests. Primary instrumentation consisted of the following:

Station	Location	Instrumentation
0	Ambient	Ambient pressure Ambient temperature
1	Bellmouth Throat	4 wall static pressures, 90° apart
3	Compressor Discharge	4 wall static taps, 90° apart 4 total temperatures
3	Combustor Inlet	4 wall static pressures
6	Turbine Exit	4 wall static pressures, 90° apart 4 total temperatures
8	Nozzle Throat	4 element exit total pressure rake

Other instrumentation included:

- o Rotational speed-magnetized nut and horseshoe collar
- o Fuel flow to primary burner
- o Fuel flow to augmentor
- o Thrust (load cell)

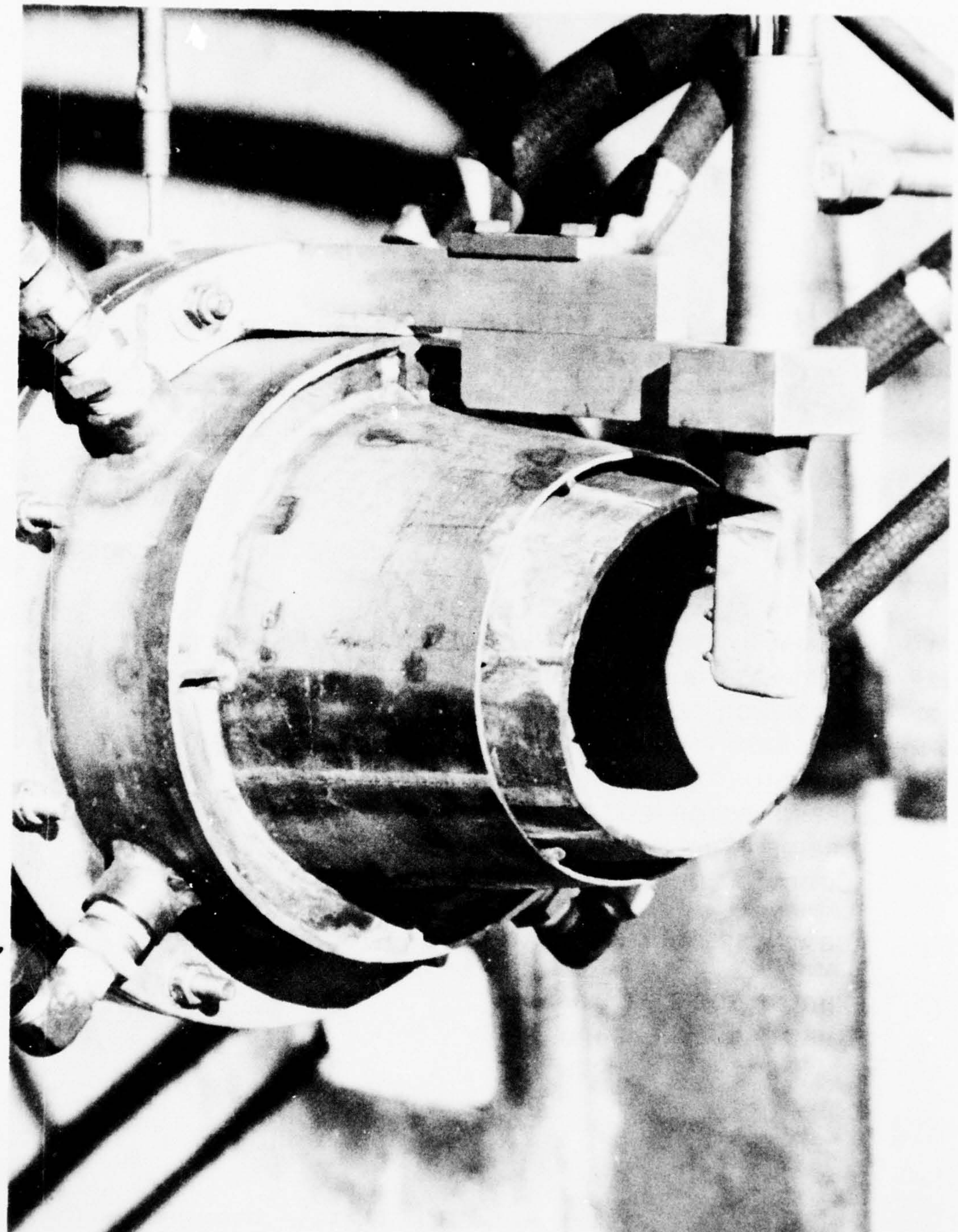

Figure 42. Installed Water-Cooled, Exit-Total-Pressure Rake.

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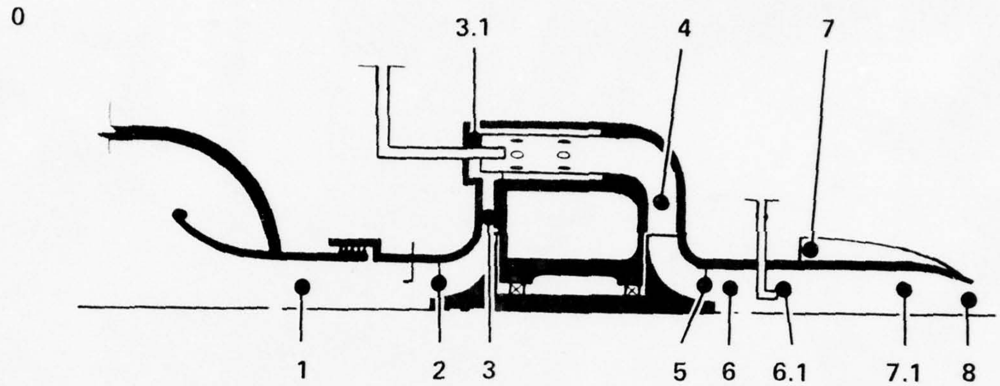

0	AMBIENT, BELLMOUTH INLET
1	BELLMOUTH THROAT, COMPRESSOR HOUSING INLET
2	COMPRESSOR ROTOR INLET PLANE
3	COMPRESSOR DISCHARGE (PLENUM)
3.1	COMBUSTOR PLENUM DOME
4	COMBUSTOR DISCHARGE, TURBINE INLET (TORUS)
5	TURBINE ROTOR EXIT PLANE
6	TURBINE EXHAUST FLANGE PLANE
6.1	AUGMENTOR DUCT IMMEDIATELY UPSTREAM OF SUDDEN EXPANSION PLANE
7	AUGMENTOR DUCT IMMEDIATELY DOWNSTREAM OF SUDDEN EXPANSION PLANE
7.1	EXHAUST NOZZLE ENTRANCE
8	EXHAUST NOZZLE EXIT PLANE

Figure 43. ETJ131 Model 103 Station Designations.

- Augmentor skin temperature (3 places)
- Cooling flow temperature

3. Development Testing

The first test of the water-cooled augmentor was successfully accomplished on January 14, 1977. A light-off was achieved on the first attempt.

To provide a synopsis of the test procedure, the first run of the augmentor will be described. The engine, without the augmentor lit, was started and stabilized at an exhaust gas temperature 150°F below the normal maximum. This was done to provide a margin since augmentor light-off without variable nozzle area results in an increase in turbine inlet temperature and a decrease in speed. Fuel flow to the augmentor was 190 pounds per hour when light-off occurred. Engine thrust observed before light-off was 73 pounds and increased to 100 pounds after light-off.

Water flow to the augmentor and nozzle was 83 gpm. Augmentor metal temperatures ranged from 95°F forward to 160°F aft. After light-off, the temperature increased approximately 100°F and engine speed dropped approximately 4000 rpm. On shutdown, the blowout point was between 130 and 150 pph. In subsequent tests, whenever augmentor fuel flow was increased, engine speed was decreased to provide margin for the temperature rise. After the augmentor was stabilized, speed was increased to bring the temperature back to the normal maximum.

Following the initial checkout tests, a systematic investigation to determine the following was undertaken:

- Augmentor performance
- Nozzle characteristics
- General operating characteristics

Three nozzle areas were investigated to provide data for a nozzle calibration. Test data with the augmentor lit was not acquired with the small nozzle (11.82 square inches). The other two nozzle areas tested were 14.28 square inches and 15.36 square inches. It should be noted that the performance of the basic ETJ131 with augmentor is lower than that predicted for the Model 1030. This is due to the lower flow rate of the ETJ131 and the low pressure into the augmentor due to lower turbine inlet temperature. Test results for the intermediate nozzle area (14.28 square inches hot) with the augmentor lit are shown in Table 9. The data is not presented graphically, as speed and augmentor temperature (matching variables) are not constant. There is generally good correlation of tested and predicted values. Thrust, TSFC, speed, and temperature have been corrected to standard day. Also shown is augmentor efficiency calculated from test data and predicted levels. Table 10 shows similar results for the large nozzle area (15.36 square inches hot). This data shows more variation from the predicted data than the results for the smaller nozzle area, though correlation is still very reasonable. Tested augmentor efficiency versus overall fuel/air ratio is shown in Figure 44. The tested augmentor average efficiency is approximately 0.88 as compared to a predicted value of 0.868.

Much of the testing was done to check the performance of the engine in the non-augmented mode and to calibrate the exhaust nozzles. Figures 45, 46, and 47 compare non-augmented tested performance with predicted non-augmented performance for the tested nozzle areas. The correlation between tested and predicted performance is good. Nozzle thrust coefficients were calculated based on this data and are shown in Figure 48.

TABLE 9. LOW-COST SUBSONIC ENGINE (ETJ131) AUGMENTED OPERATION WITH AN INTERMEDIATE NOZZLE AREA OF 14.28 SQUARE INCHES CORRECTED TO SEA-LEVEL, ISA.

ENGINE SPEED (RPM)	TEST DATE	T_7/θ_{t2} AUGMENTOR TEMPERATURE (°F)	η_{AB}		F_N/δ_2 (LB)		$TSFC/\sqrt{\theta_2}$ (LB/HR/LB)	
			ANALYTICAL	TEST	ANALYTICAL	TEST	ANALYTICAL	TEST
64,191	3-11-77	2715	0.867	0.886	87.4	90.4	3.34	3.089
64,790	3-11-77	3190	0.868	0.902	102.0	106.0	3.618	3.312
64,191	3-11-77	3266	0.868	0.832	102.0	110.0	3.492	3.442
64,670	3-11-77	3413	0.868	0.896	107.0	113.0	3.547	3.456
68,892	3-14-77	2905	0.868	0.852	108.0	113.0	3.01	3.039
69,674	3-14-77	2991	0.868	0.941	113.0	117.0	3.02	2.955
69,907	3-14-77	2999	0.868	0.857	114.0	119.0	3.09	3.045
63,716	2-25-77	3136	0.868	0.900	98.0	103.0	3.326	3.374
63,298	3-7-77	3244	0.868	0.914	99.0	102.0	3.427	3.347
59,166	3-7-77	3278	0.868	0.727	83.7	85.5	3.767	4.257

AD-A067 277 AIRESEARCH MFG CO OF ARIZONA PHOENIX F/G 21/5
ALTERNATE SUBSONIC LOW-COST ENGINE.(U)
MAY 78 C F BAERST, J W SANDBORN F33615-76-C-2063
UNCLASSIFIED 76-212199(21) AFAPL-TR-78-31 NL

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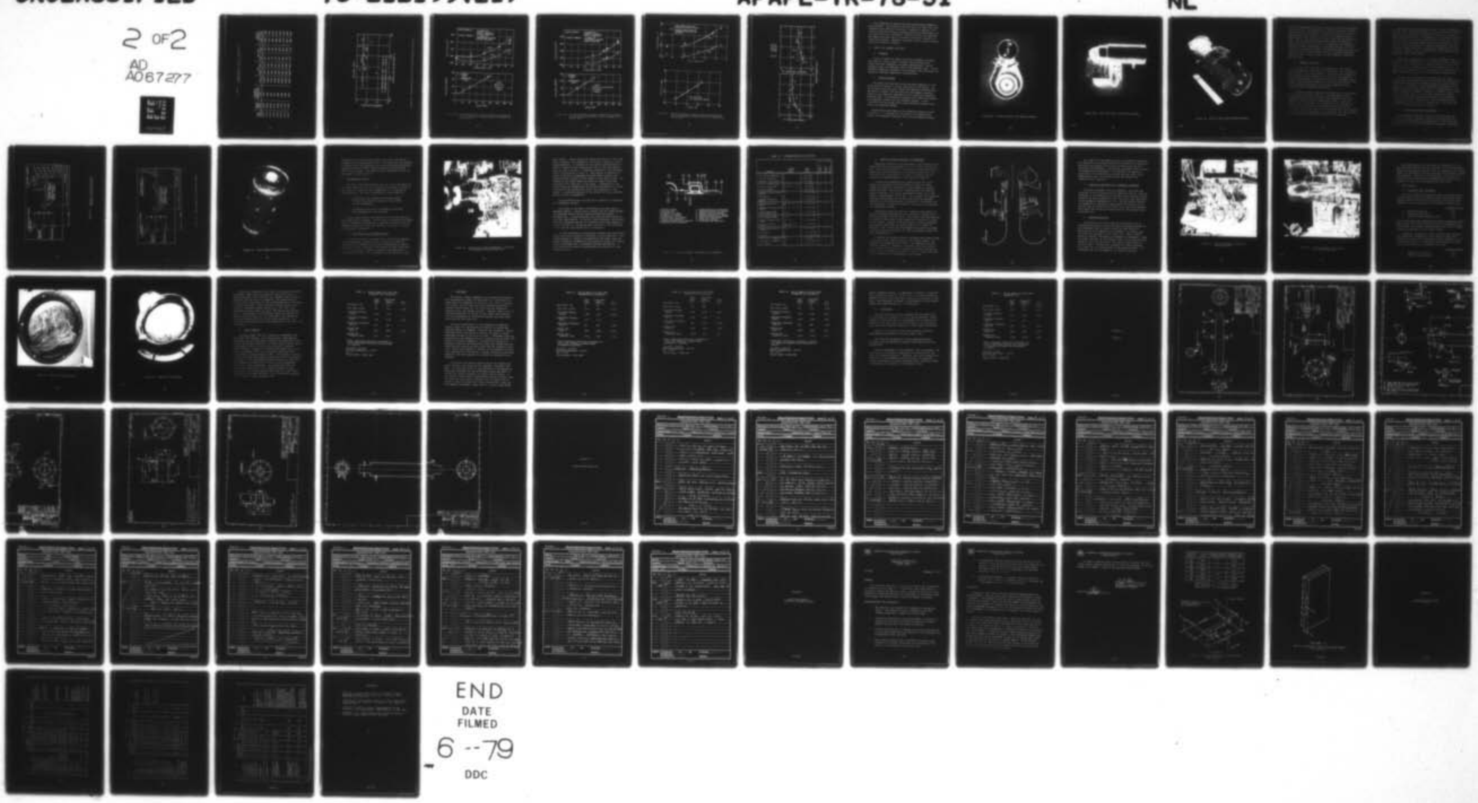

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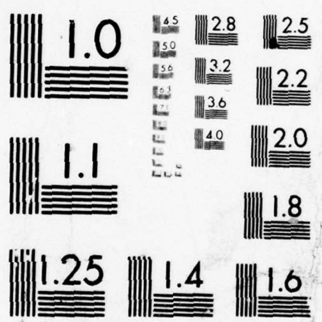


MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 10. AUGMENTOR PERFORMANCE TEST RESULTS
NOZZLE AREA = 15.36 SQ. IN.

TEST DATE	ENGINE SPEED (RPM)	REFERRED AUGMENTOR TEMPERATURE (^oF)	$(F/A)_{OV}$	η_{AB}		F_N/δ (LB)		$TSFC/\sqrt{\theta}$ (LB/HR/LB)	
				ANAL.	TEST	ANAL.	TEST	ANAL.	TEST
5-5-77	65,497	2732	0.0506	0.868	0.870	93.7	91.2	3.670	3.788
5-5-77	66,334	3022	0.0544	0.868	0.949	104.2	100.0	3.791	3.764
5-5-77	66,036	2627	0.0453	0.868	0.993	92.8	85.0	3.567	3.545
5-5-77	71,417	2772	0.0532	0.868	0.815	114.7	116.0	3.361	3.495
5-5-77	71,590	2600	0.0493	0.868	0.823	109.7	110.0	3.252	3.434
5-5-77	71,766	2388	0.0443	0.864	0.836	103.2	105.0	3.115	3.259
5-5-77	71,647	2099	0.0422	0.853	0.628	93.2	102.0	2.947	3.209
5-5-77	71,544	2819	0.0537	0.868	0.844	116.6	118.0	3.382	3.501

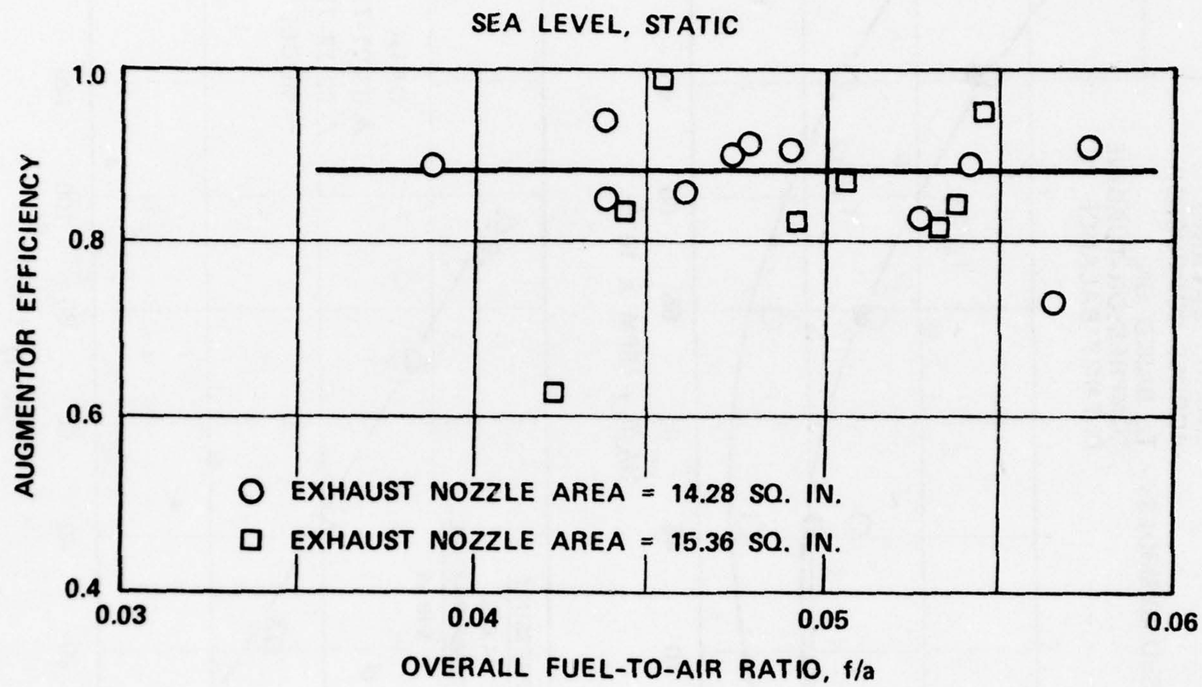


Figure 44. Tested Performance ETJ131 Sudden Expansion Augmentor.

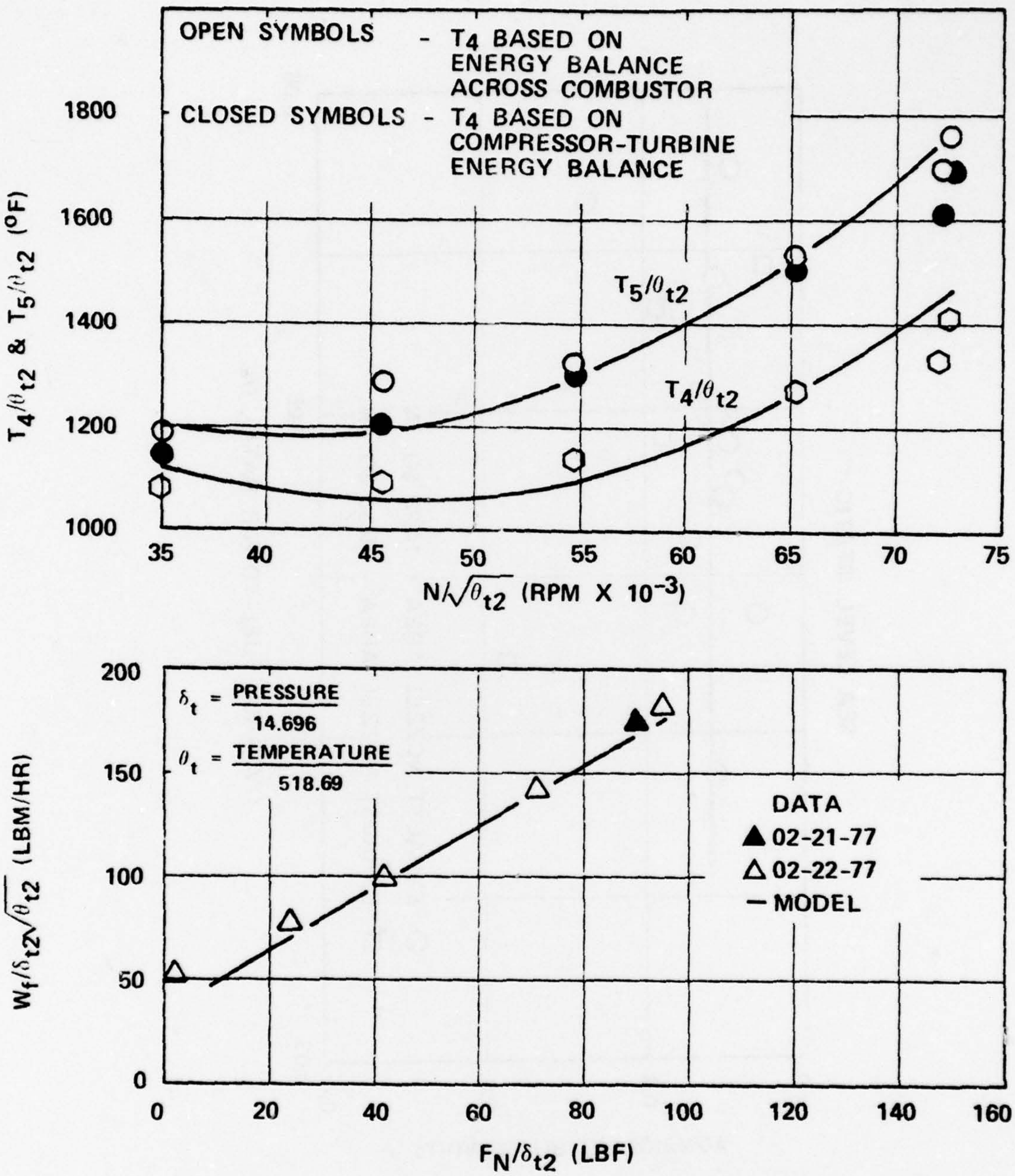


Figure 45. Tested Performance Versus Predicted Performance for Non-Augmented Operation with a 11.82 Sq. In. Nozzle Area.

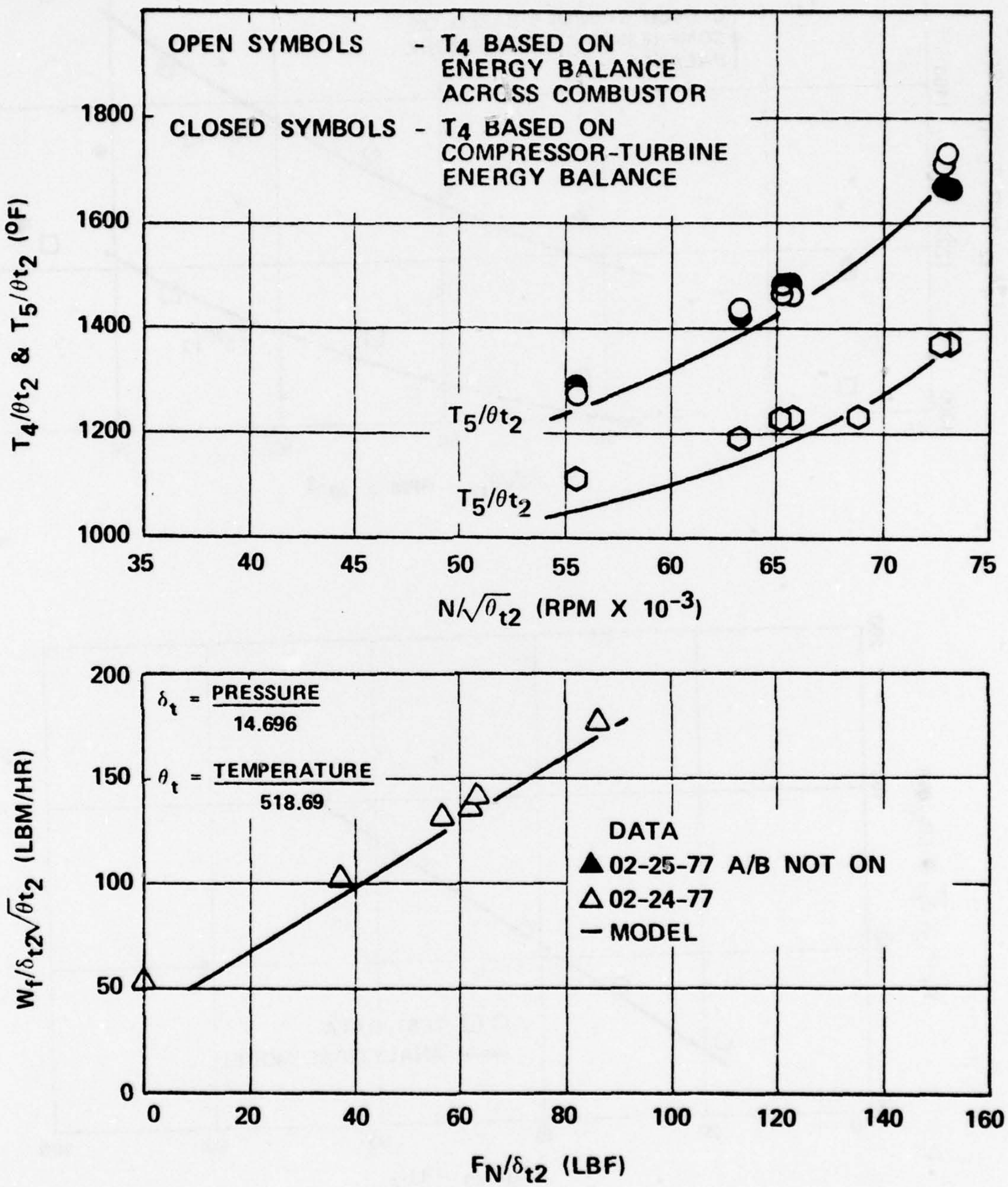
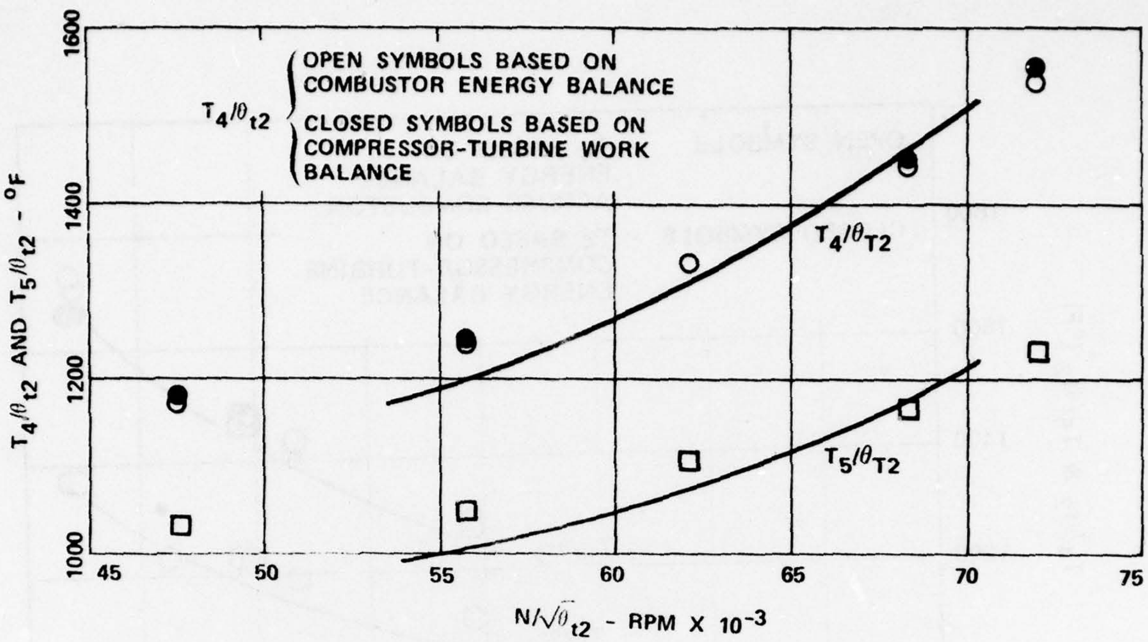


Figure 46. Tested Performance Versus Predicted Performance for Non-Augmented Operation with a 14.28 Sq. In. Nozzle Area.



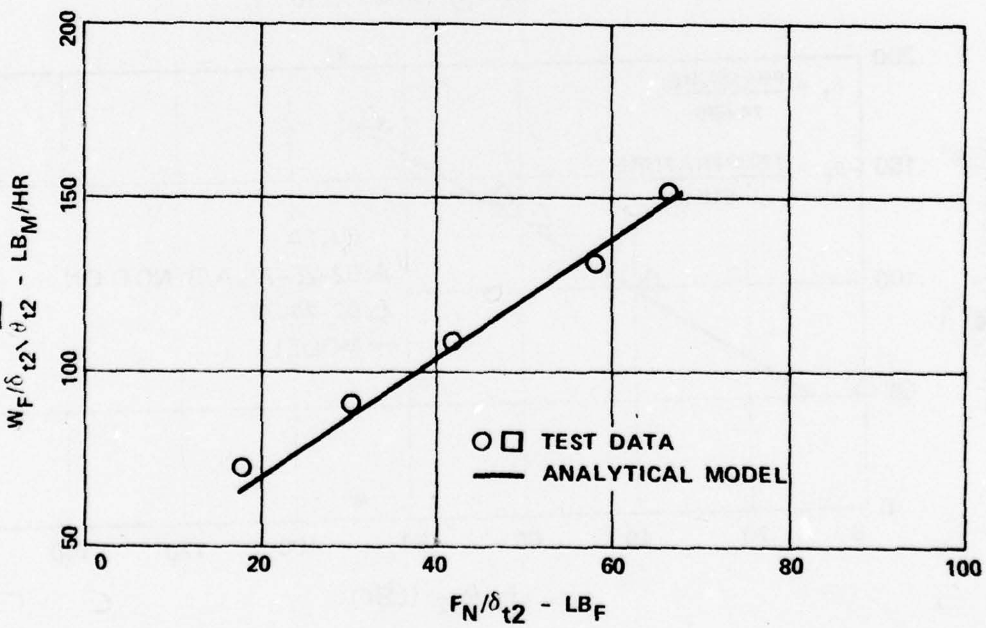


Figure 47. Tested Performance Versus Predicted Performance for Non-Augmented Operation with 15.6 Square-Inch Nozzle Area.

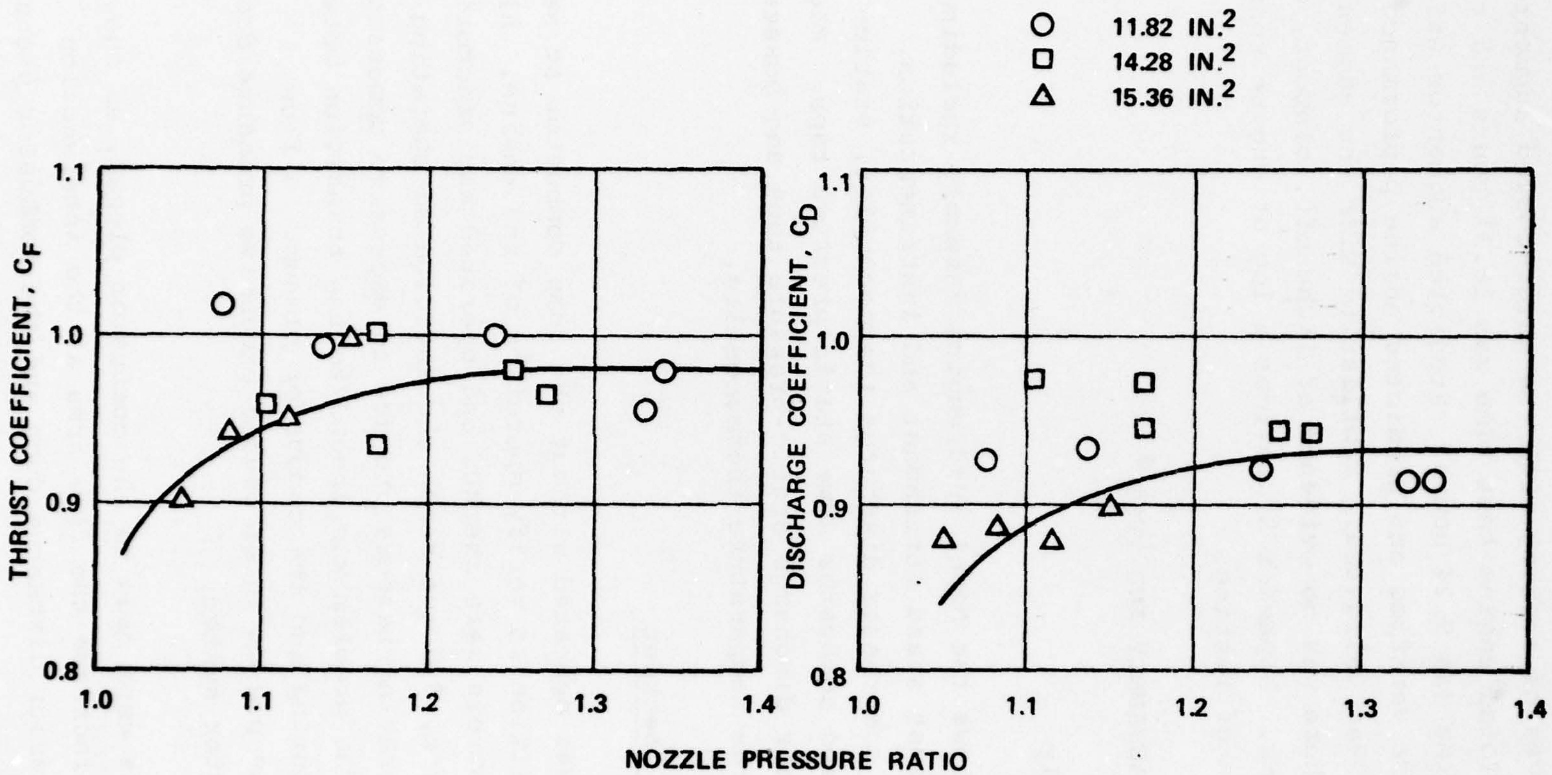


Figure 48. Calculated Nozzle Thrust Coefficients.

The objectives of testing with the water-cooled augmentor were achieved. Total engine test time was 16.31 hours and total augmentor test time was 9.24 hours. Predicted augmentor efficiency levels were verified and predicted engine performance for the basic ETJ131 was validated. Familiarity with the augmentor was gained and there was no evidence of light-off, blowout, or stability problems. Appendix B provides a log of engine running during this phase of testing.

5. MODEL 1030 ASSEMBLY AND TEST

a. Assembly

Figure 49 shows the Model 1030 engine assembly including the plate for thrust stand attachment and instrumentation. Figure 49A shows compressor discharge thermocouples, static-pressure tubes, and combustor dome static-pressure taps. Figure 49B shows combustor discharge static-pressure taps and bosses for combustor discharge temperature thermocouples.

b. Engine Checkout

The engine was operated without the dump combustor at sea-level static condition to verify operation of the engine. All of the manual controls were checked and operated satisfactorily. The engine, however, did not reach the anticipated operating speed for the operating temperature due to excessive combustor pressure drop. The problem was traced to the transition between the compressor housing and the combustor plenum. A flow restriction at the plenum inlet caused excessive pressure drop across the combustor system.

Modifications were made to the combustor plenum, as shown in Figure 50, to increase the flow area at the intersection between the compressor discharge duct and the combustor plenum.

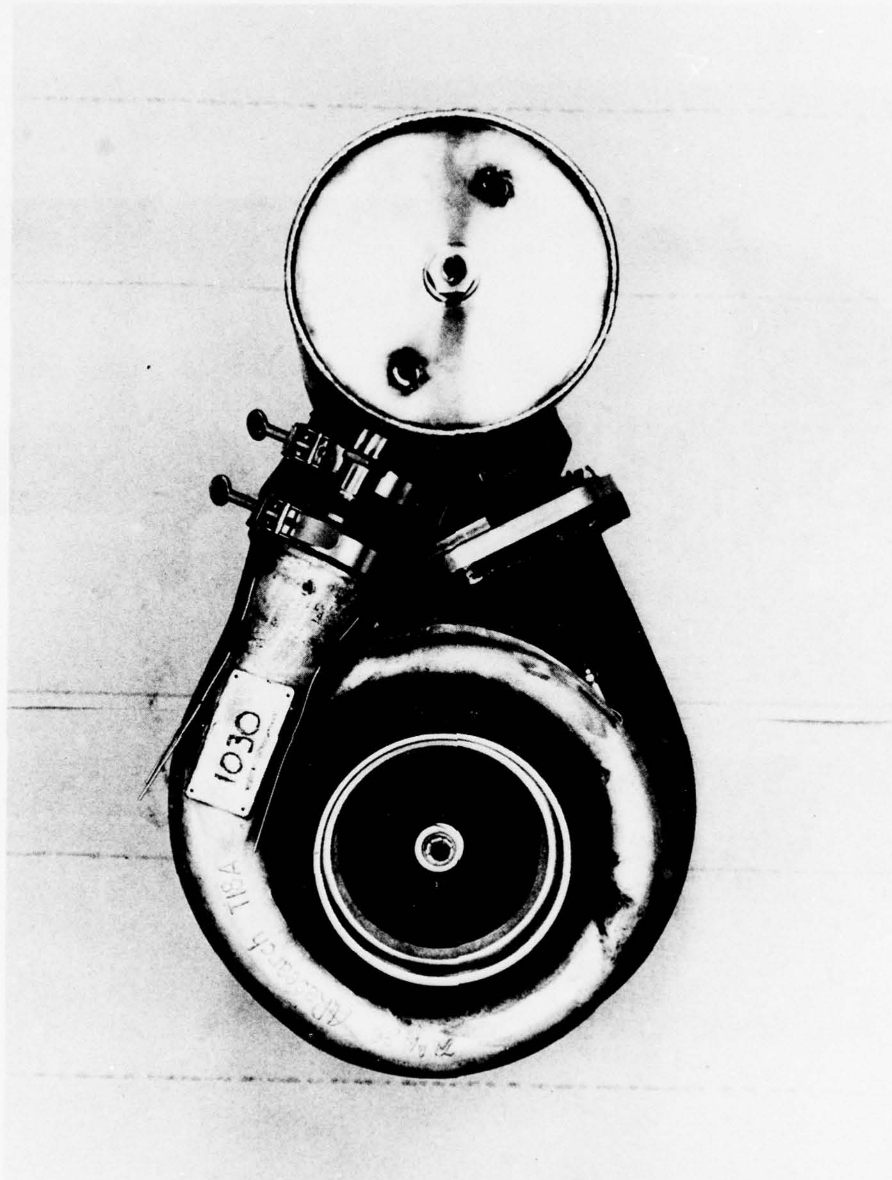


Figure 49A. Front View Model 1030 Engine Assembly.

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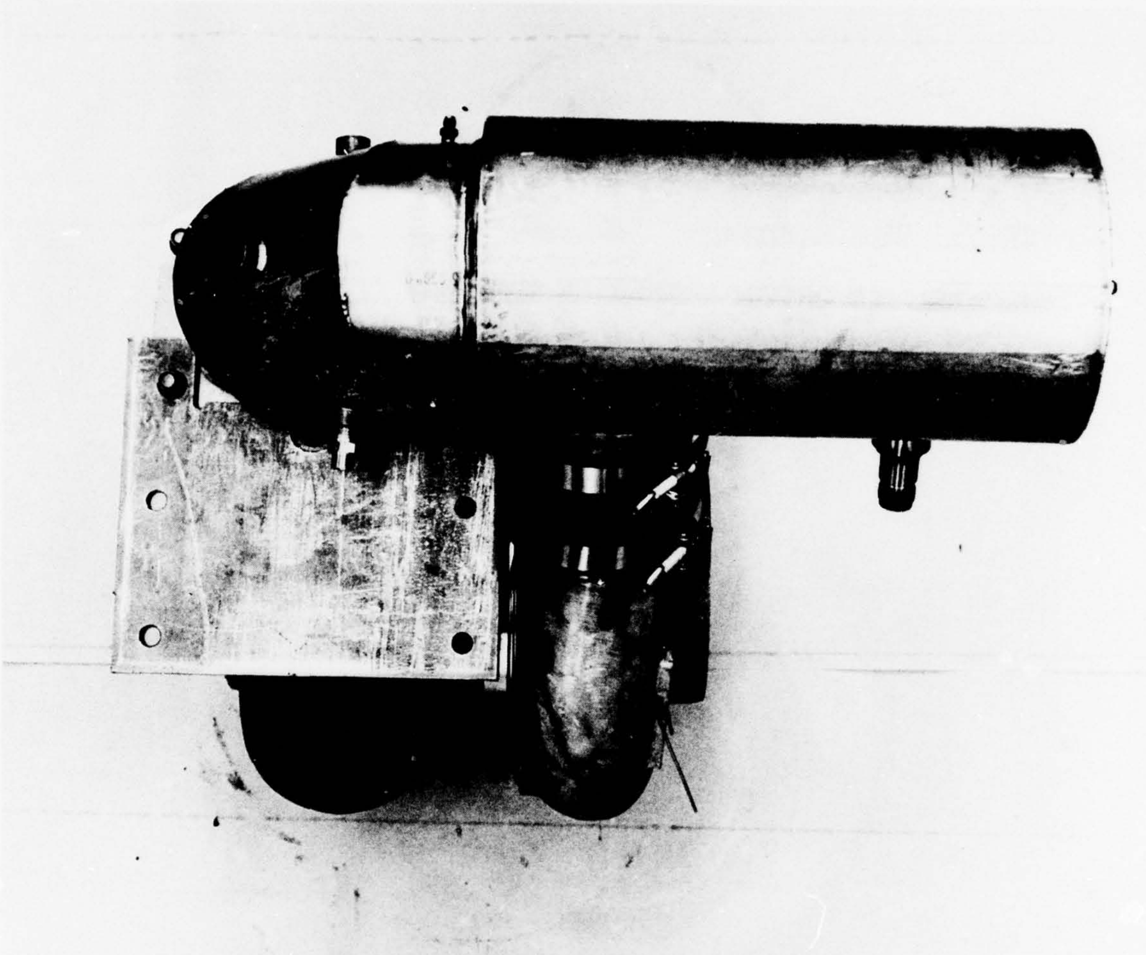

Figure 49B. Side View Model 1030 Engine Assembly.

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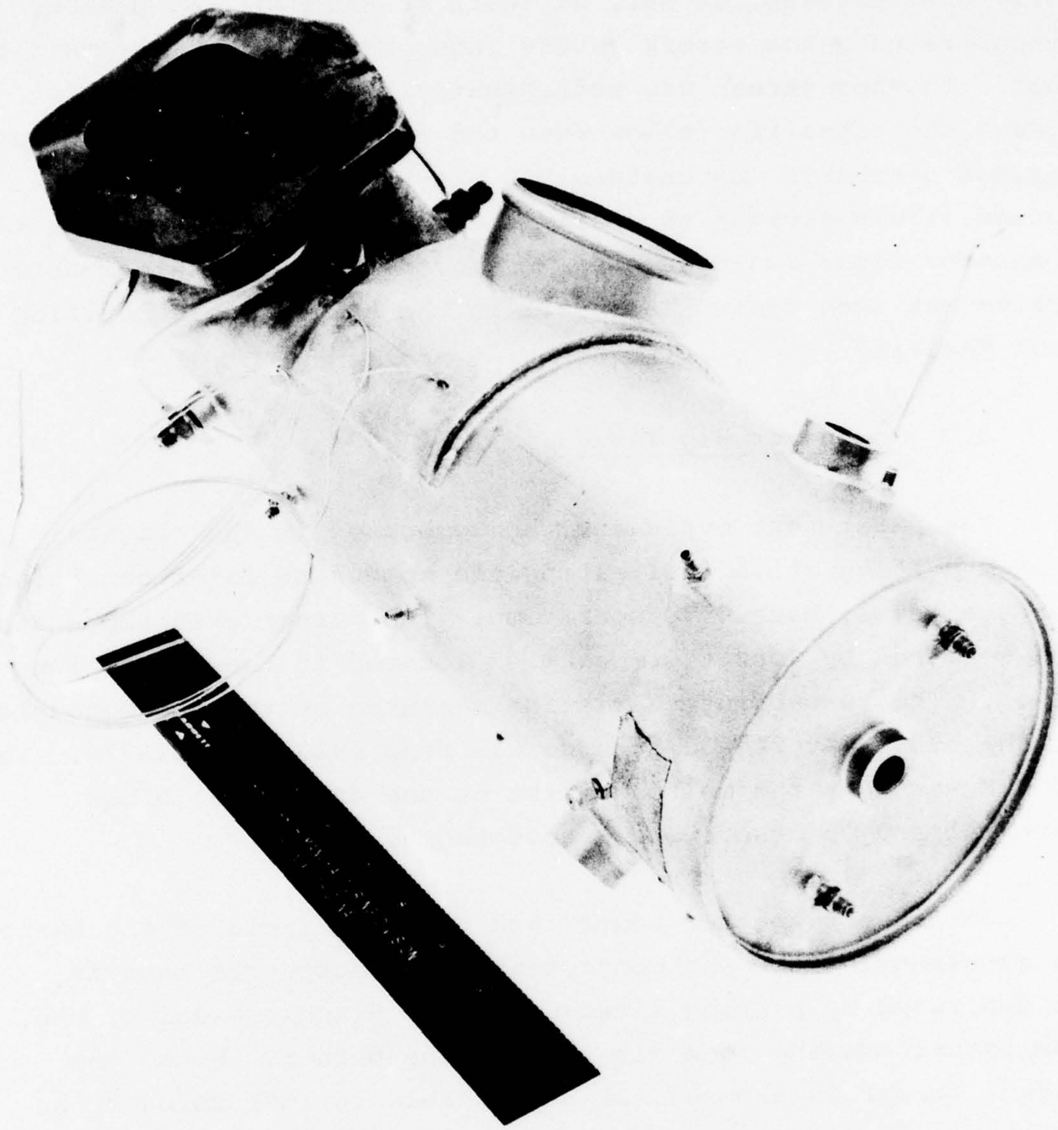


Figure 50. ETJ131, Model 1030 Modified Combustor.

MP-61290

This was accomplished by locally increasing the plenum-combustor channel height. This modification cured the excessive pressure drop problem but accentuated a temperature distribution problem. Early engine tests, as well as tests of the modified plenum, demonstrated a hot streak on the inner radius of the transition duct. The hot streak was sufficiently high to structurally damage the transition elbow when the combustor was operated at maximum discharge temperature for extended periods. For this reason it was decided to modify the engine hardware such that the combustor liner could be easily removed. The entire combustor system was then tested as a unit in the AiResearch Combustion Test Facility.

c. Combustor Rig Tests

The first test evaluated the combustor in the original engine configuration duplicating the combustor inlet conditions for sea level, Mach 0.7, operation. The burner exit temperature was measured by four thermocouples located in the transition elbow. The temperature variation measured by the thermocouples at the 1900°F average discharge was from 1520°F to 2257°F. The 2257°F was near the melting point of the transition elbow material and was therefore unacceptable.

In order to better understand the flow field of the burner, an atmospheric test was conducted. An atmospheric test is accomplished by pulling a vacuum on the discharge end of the combustor, drawing room air through the burner. Since the burner itself is exposed, it is possible to look through the various combustor orifices and observe the flame type and position. During this test, it was determined that the vaporizer was not functioning properly and the operation was very sensitive to the alignment of the fuel tube inside the vaporizer.

The vaporizer was redesigned to ensure correct alignment of the fuel tube. The fuel injection tube tip was changed from one axial orifice to six radial orifices to improve the circumferential fuel distribution. The atomizer was increased in size for greater airflow and the small twelve dome orifices were removed since they were no longer needed with the new vaporizer. The ensuing test revealed that the discharge temperature variation had been reduced along with a reduction in combustor wall temperatures. However, the hot streak on the inner radius of the transition liner still existed.

Four rows of five orifices, 0.2 inch in diameter, were drilled at the discharge end of the transition liner as shown in Figure 51. These small orifices were to provide a film of air that would cool the inside radius of the transition liner. In addition, the diameter of the dilution holes was reduced and the number increased from six to twelve for more uniform mixing.

Testing of this configuration showed that the local cooling holes did reduce the transition elbow wall temperatures substantially on the inner radius, causing the outer radius to become hot. Therefore, a final modification was made to distribute the cooling holes around the full circumference of the burner discharge, as shown in Figure 52. Testing of this burner at the sea-level, Mach 0.7, simulated conditions produced acceptable discharge temperature distribution and attendant transition liner wall temperatures. This configuration was recommended for use in the full engine tests. The final combustor configuration is shown in Figure 53.

d. <u>Compressor and Turbine Rig Tests</u>

The AiResearch Industrial Division rig tested the compressor and turbine, including the new turbine housing, as a unit, and provided updated performance maps. These were compared with the estimated maps previously supplied. Compressor

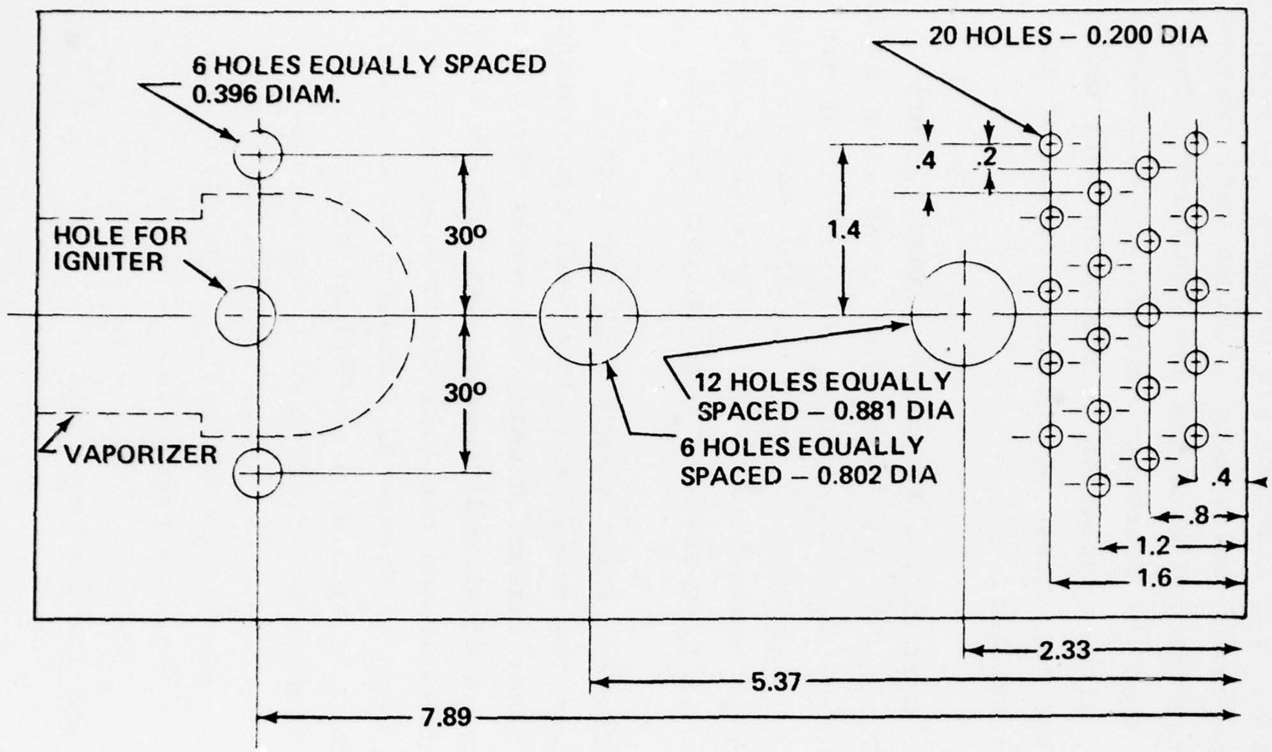


Figure 51. Combustor Configuration with Localized Cooling Orifices.

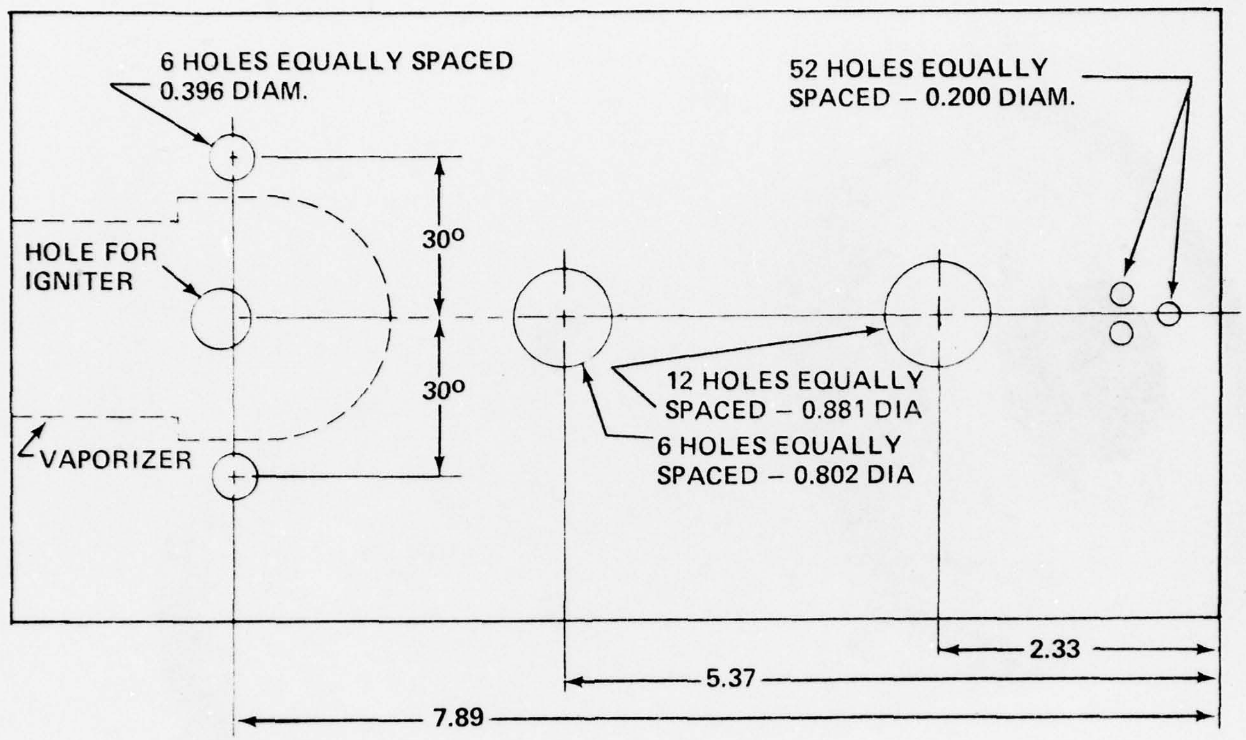


Figure 52. Final Combustor Configuration Design.

Figure 53. Final Combustor Configuration.

efficiency was unchanged and turbine efficiency decreased by 7 points at the engine design point. The reason for the decrease in turbine efficiency could not be explained without significant testing and analysis which were not judged to be within the scope of the program. The effect of this efficiency change is discussed in a later section.

6. DEMONSTRATION TESTING

The goal of the demonstration test was to run the engine at sea-level, Mach 0.7, for thirty minutes and produce a thrust of 200 pounds at a specific fuel consumption of 3.07 pounds-per hour-per-pound. The actual demonstration was preceded by:

- Installation and checkout of the Model 1030, without the augmentor installed, at sea-level and ram conditions

- Performance tests with the augmentor installed but inoperative at ram conditions

Total running time of the engine in the altitude facility was 5 hours and 31 minutes. Of this time, 47 minutes were logged with the augmentor installed and 6 minutes were logged with the augmentor operating. Test logs covering this phase of testing are included in Appendix C.

a. Installation and Checkout Testing

The installation of the Model 1030, without the augmentor, in the AiResearch altitude facility is shown in Figure 54. Installation and checkout testing was accomplished at nominal sea-level, static conditions. The purpose of these tests were to checkout the data acquisition system, gain experience in operating the engine, and to determine the performance of the

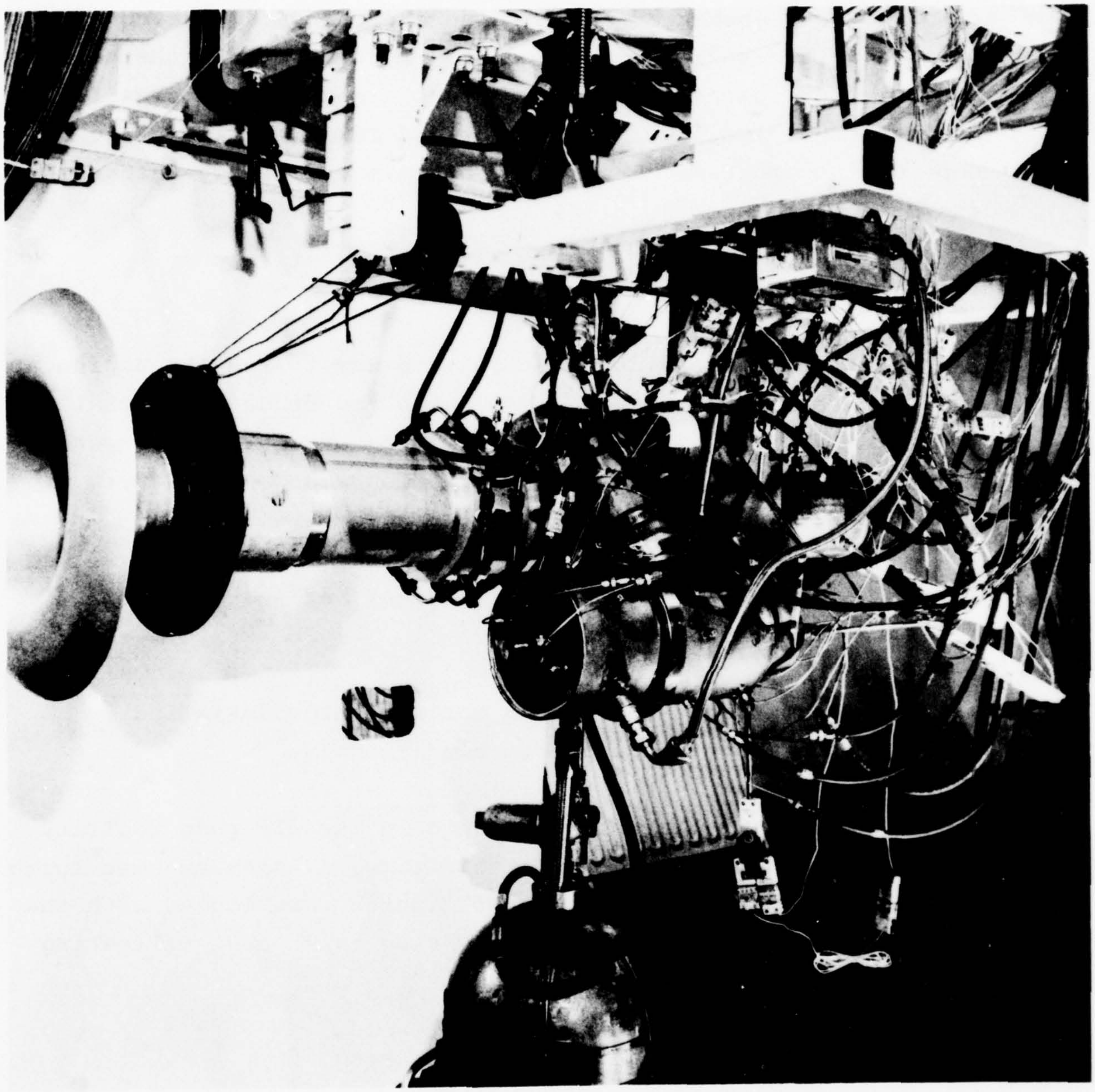


Figure 54. Model 1030, without Augmentor, Installed in AiResearch Altitude Facility.

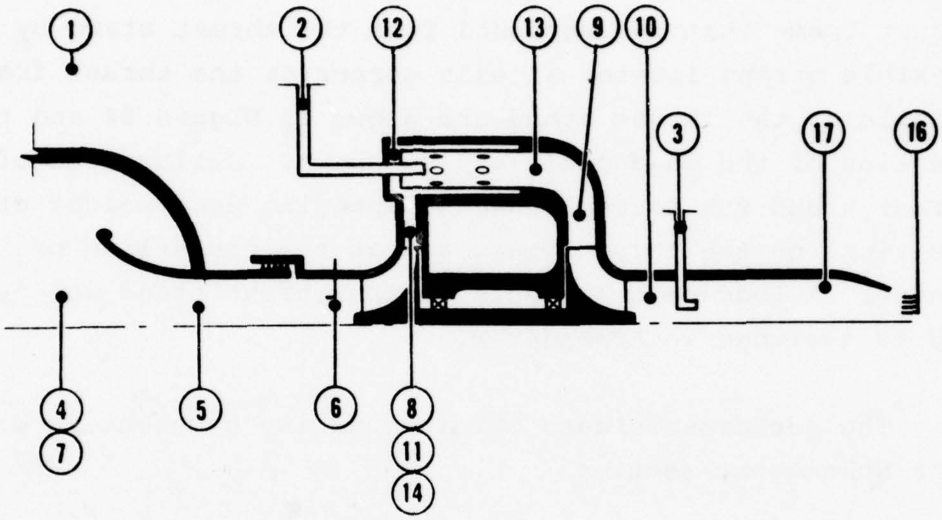
MP-61904

basic engine. Engine airflow was taken from the cell, which was open to ambient, and directed to the engine by means of a calibrated bellmouth. A schematic of the engine instrumentation is shown in Figure 55 and a descriptive list of this instrumentation is given in Table 11. Recording methods for the instrumentation is also given in Table 11. This engine is mounted on a thrust frame that is suspended from the thrust stand by four flexible straps located at each corner of the thrust frame. The details of the thrust stand are shown in Figure 54 and the position of the load cell is also shown. Calibration of the thrust stand was accomplished by applying dead weight at various positions on the thrust frame and at the centerline of the engine. A load-path analysis of the thrust stand was performed and is included in Appendix B.

The performance data obtained during checkout is discussed in a subsequent section.

One change to the engine configuration was made during checkout testing. Initial tests revealed that the elbow between the combustor outlet and the turbine housing was running extremely hot. It was determined that this was being caused by poor fuel distribution. To correct this deficiency, the injector tube was lengthened and the six injection holes were changed to inject the fuel at a 45-degree angle relative to the centerline of the injector tube rather than at 90 degrees.

No other mechanical or operational problems were encountered during the initial testing at sea-level, static conditions. The limited amount of internal instrumentation did reveal some component performance differences from predicted values, but overall engine performance met or exceeded predicted performance. A more detailed discussion of performance may be found in a subsequent section.



1. BAROMETRIC PRESSURE
2. ENGINE FUEL FLOW
3. AFTERBURNER FUEL FLOW
4. BELLMOUTH TOTAL PRESSURE
5. BELLMOUTH STATIC PRESSURE
6. COMPRESSOR INLET TOTAL PRESSURE
7. INLET AIR TOTAL TEMPERATURE
8. COMPRESSOR DISCHARGE TOTAL TEMPERATURE
9. TURBINE INLET TOTAL TEMPERATURE
10. TURBINE DISCHARGE TOTAL TEMPERATURE
11. COMPRESSOR DISCHARGE TOTAL PRESSURE
12. COMBUSTOR INLET STATIC PRESSURE
13. COMBUSTOR DISCHARGE STATIC PRESSURE
14. COMPRESSOR DISCHARGE STATIC PRESSURE
15. TURBINE INLET STATIC PRESSURE
16. EXHAUST TOTAL PRESSURE
17. AFTERBURNER TOTAL TEMPERATURE

Figure 55. Altitude Chamber Instrumentation Schematic.

TABLE 11. INSTRUMENTATION AND SERVICES.

Parameter	Parameter and Station	Range and Units	Type of Service		
			Analog (Sanborn)	Digital Computer	Visual Information
Inlet ambient temperature	T_o	0 to 100°F	X	X	X
Inlet air temperature	T_{t1}	-100 to 200°F		X	X
Compressor discharge temp.	T_{t3}	0 to 400°F		X	X
Combustor discharge temp.	T_{t4}, -1, -2, -3, -4	0 to 2000°F	X	X	X
Turbine discharge temp.	T_{t5}, -1, -2, -3, -4	0 to 2000°F	X	X	
Inlet air pressure	P_{t1}	0 to 30 psia		X	
Compressor total discharge pressure	P_{t2}	0 to 100 psig		X	X
Fuel pressure	P_f	0 to 200 psig	X	X	X
Bellmouth differential pressure	ΔP_{0-1}	0 to 20 psid		X	X
Nozzle discharge total pressure	P_{t8}, -23, -24, -25, -26	0 to 100 psig		X	
Compressor discharge static pressure	P_{s3}, -1, -2, -3, -4	0 to 100 psig	X	X	X
Combustor plenum dome static pressure (top)	$P_{s3.1_t}$	0 to 100 psig		X	
Combustor plenum dome static pressure (bottom)	$P_{s3.1_b}$	0 to 100 psig		X	
Combustor discharge static pressure	P_{s4}, -1, -2	0 to 100 psig		X	
Turbine inlet static pressure	P_{s4t}, -19, -20, -21, -22	0 to 100 psig		X	
Turbine discharge static pressure	P_{s5}	0 to 50 psig		X	
Engine speed	N	0 to 100K rpm	X	X	X
Fuel flow	W_f	0 to 1000 lb/hr		X	X
Lubricating oil temperature	T_{LO}	0 to 300°F	X	X	X
Lubricating oil pressure	P_{LO}	0 to 100 psig	X	X	X
Engine thrust	F_N	0 to 250 lb	X	X	X

b. Testing at Ram Conditions - No Augmentor

Following completion of the sea-level, static testing, the ducts for providing conditioned air to the engine were installed. This setup consisted of mounting the engine bellmouth in a plenum that receives conditioned air from the facility. The calibrated flow measurement bellmouth is isolated from the engine by a buffered labyrinth seal shown in Figure 56.

Starting was accomplished by supplying ram air to the engine at a pressure of approximately 12 inches of water, causing the engine to accelerate to and windmill at approximately 6000 rpm. Fuel was then introduced and the ignition source energized. The engine accelerated rapidly to an idle speed of approximately 50,000 rpm. Once a stable idle speed was attained, ram pressure and engine speed could be increased gradually to the desired operating condition. Performance at ram conditions, without the augmentor installed, are discussed in a subsequent section.

During this phase of testing, a turbine blade failed and caused an unbalanced condition that resulted in separation of the turbine wheel from the shaft. The turbine had been operated in excess of four hours, which exceeds the 30-minute life goal of the engine. Unlike the deterioration of engine performance that results from blade tip erosion after 4 to 5 hours of operation, this failure was more sudden and resulted in damage to other parts of the engine, the test rig exhaust system, and some instrumentation.

Following the turbine failure, the engine was rebuilt using a new center body, seals, bearings, and rotating group. The combustor was undamaged and re-used. The compressor housing, although rubbed, was machined, refinished, and also re-used. Less than six man-hours were required to teardown, perform the repairs, and re-assemble the engine. This is a good indication of the simplicity and ruggedness of this engine.

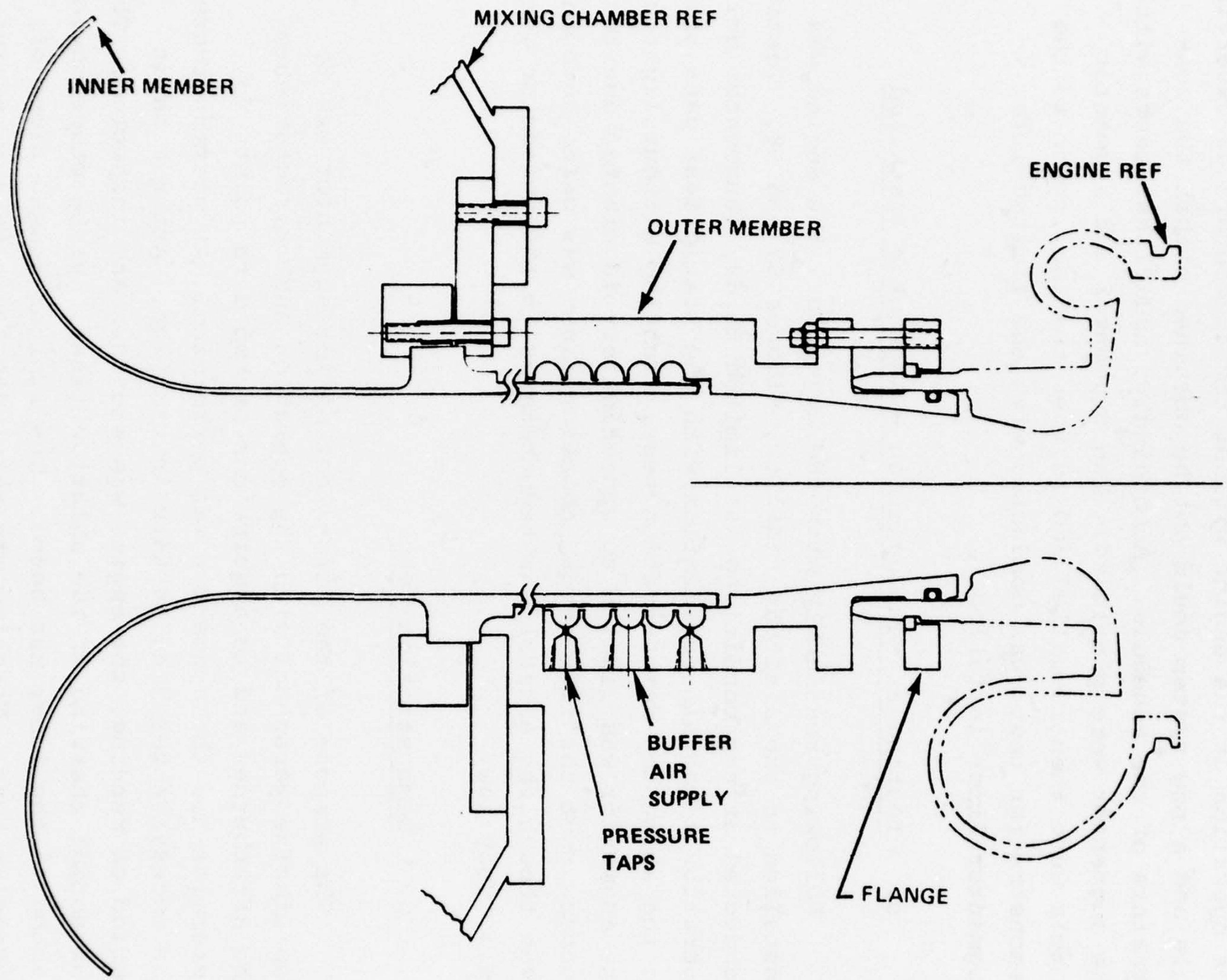


Figure 56. Flow Measuring Bellmouth Installation.

As a result of the turbine failure, the exhaust system used for operation of the engine without the augmentor was unserviceable and a new system could not be obtained within the constraints of the schedule. Accordingly, additional tests without the augmentor were precluded. The augmentor and augmentor nozzle were then installed and further testing, prior to the demonstration test, was conducted with the limited-life augmentor liner installed.

c. Testing at Ram Condition - Augmentor Installed

Following reassembly with the augmentor, the engine was installed in the altitude facility, Figures 57 and 58. Testing conducted at ram conditions was limited to dry (augmentor unlit) operation to obtain correlation with the static test data prior to the augmentor demonstration test. Testing without lighting the augmentor was limited to approximately 40 minutes due to concern that the life of the ablative liner was being consumed even though the exhaust gas temperatures in the augmentor were relatively low.

d. Demonstration Test

The purpose of the first test of the augmentor was to familiarize personnel with the operation and characteristics of the afterburner and to acquire one or two data points to determine how the augmentor was performing. At startup there was excessive torching on this initial run. After a short period of running, the engine was shutdown and inspected. There was normal charring of the ablative liner, but no other obvious damage to the liner was noted. The ignitor showed signs of excessive heat. Torching was attributed to either excessive fuel supply or fuel accumulating in the uncharred liner. In a subsequent test of the augmentor, no torching occurred.

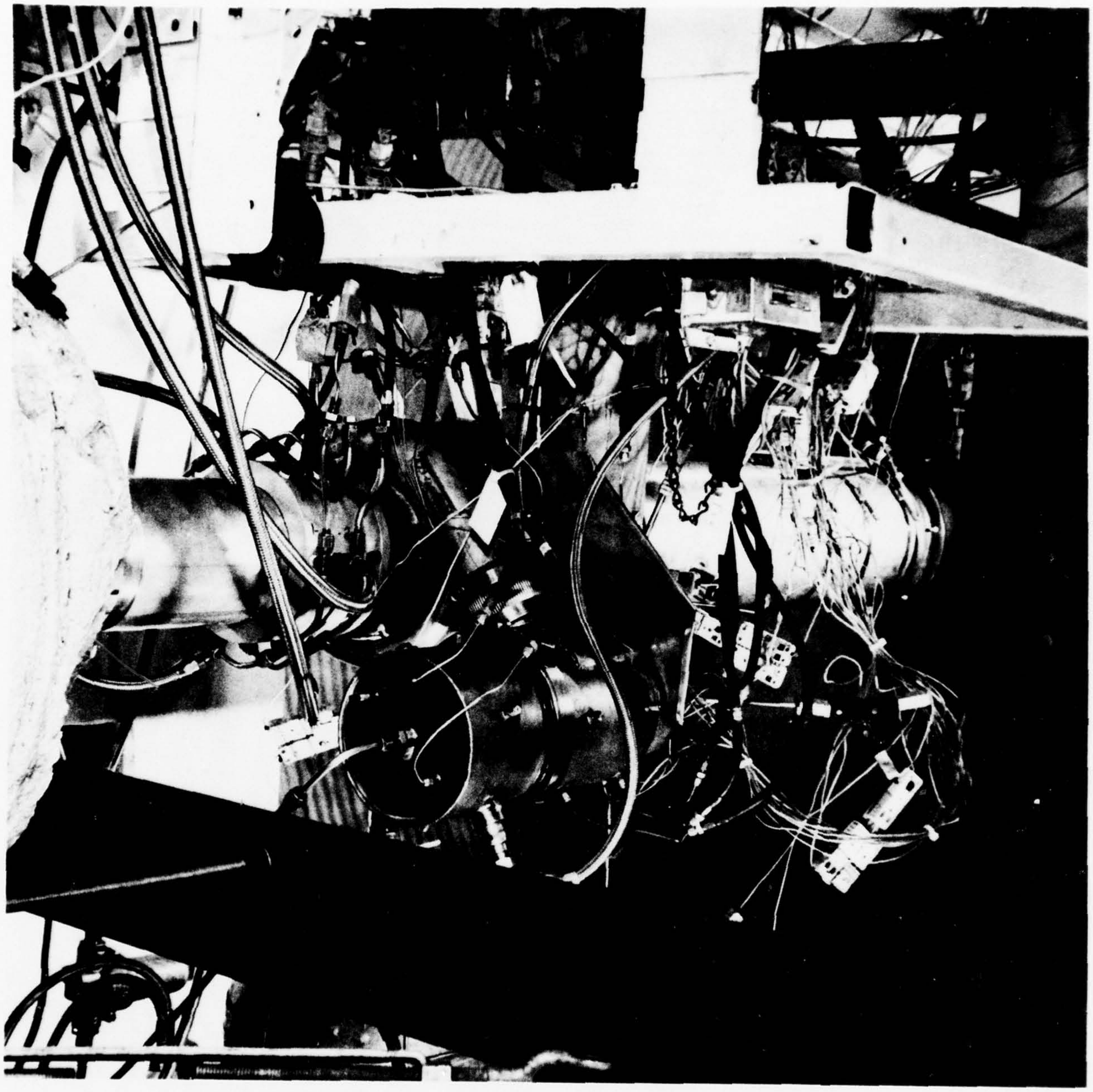


Figure 57. Altitude Chamber Installation, View Looking Aft.

MP-61903

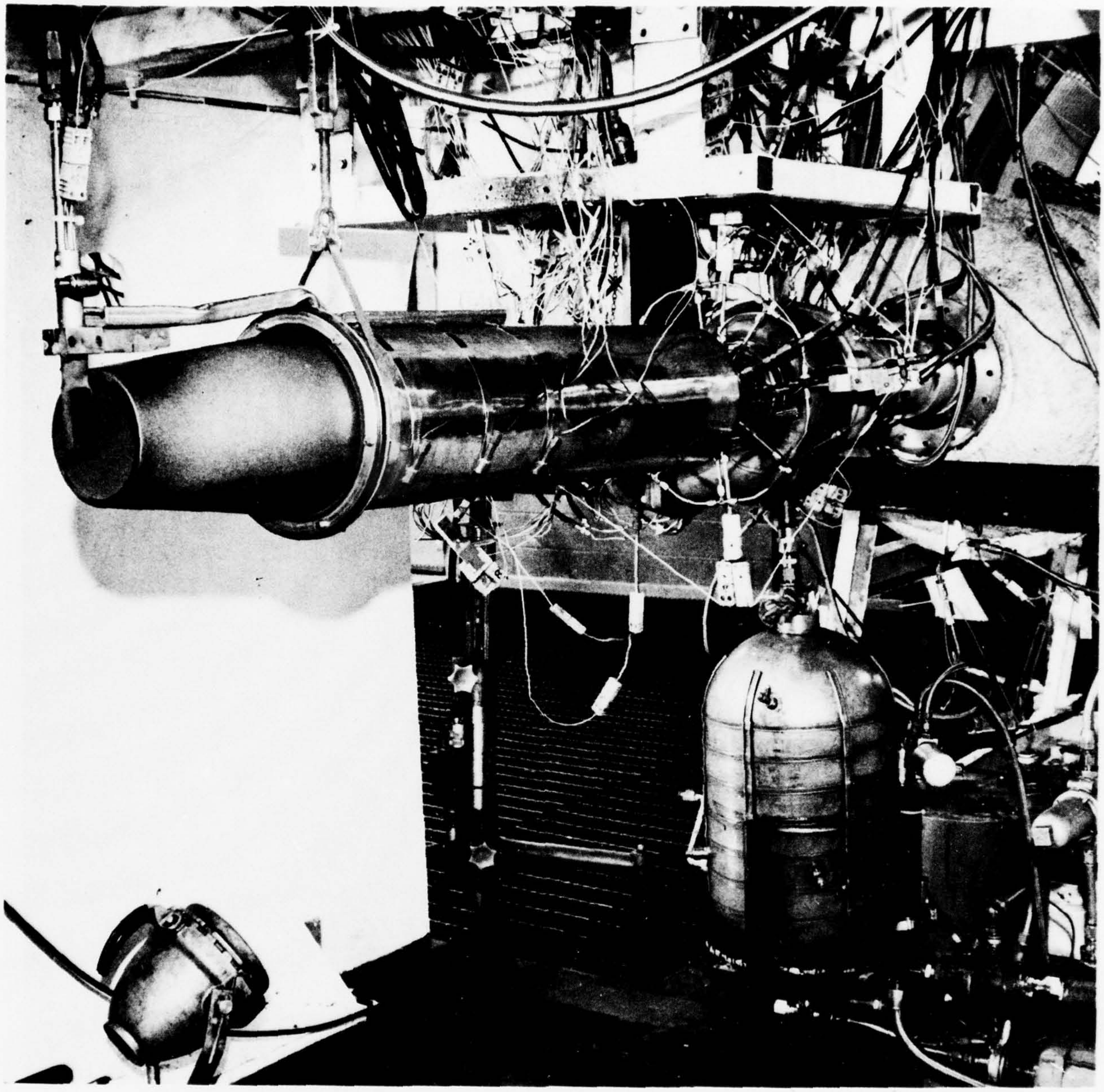


Figure 58. Altitude Chamber Installation,
View Looking Forward.

MP-61900

The demonstration test took place on December 23, 1977. The engine was started, and the augmentor lit. After approximately five minutes of operation with the augmentor lit, a large section of the ablative coating separated from the metal case of the augmentor. Inspection, after shutdown, revealed that a portion of the graphite nozzle flange had also cracked loose. Figures 59 and 60 show the damaged liner and nozzle.

7. DATA ANALYSIS

a. Analytical Model Revisions

The ETJ131 Model 1030 analytical model was revised prior to demonstration testing to improve engine performance predictions of expected test results for analysis of the test data. Component rig tests resulted in the following modifications:

	Δ, Percent Points
o Turbine efficiency	-9.0
o Mechanical efficiency	+2.0
o Turbine diffuser pressure loss	+2.0

This revised model was rematched by resizing the exhaust nozzle area to hold the original model turbine inlet temperature and rotor speed. The original exhaust nozzle area of 16.74 square inches was increased to 19.27 square inches.

Subsequent to the engine tests, the test data indicated that additional adjustments to the analytical model were required to account for differences between component rig and engine operation and for combustor configuration differences. The following additional adjustments were made:

	Δ, Percent Points
o Compressor efficiency	+2.5
o Combustor pressure drop	+2.0

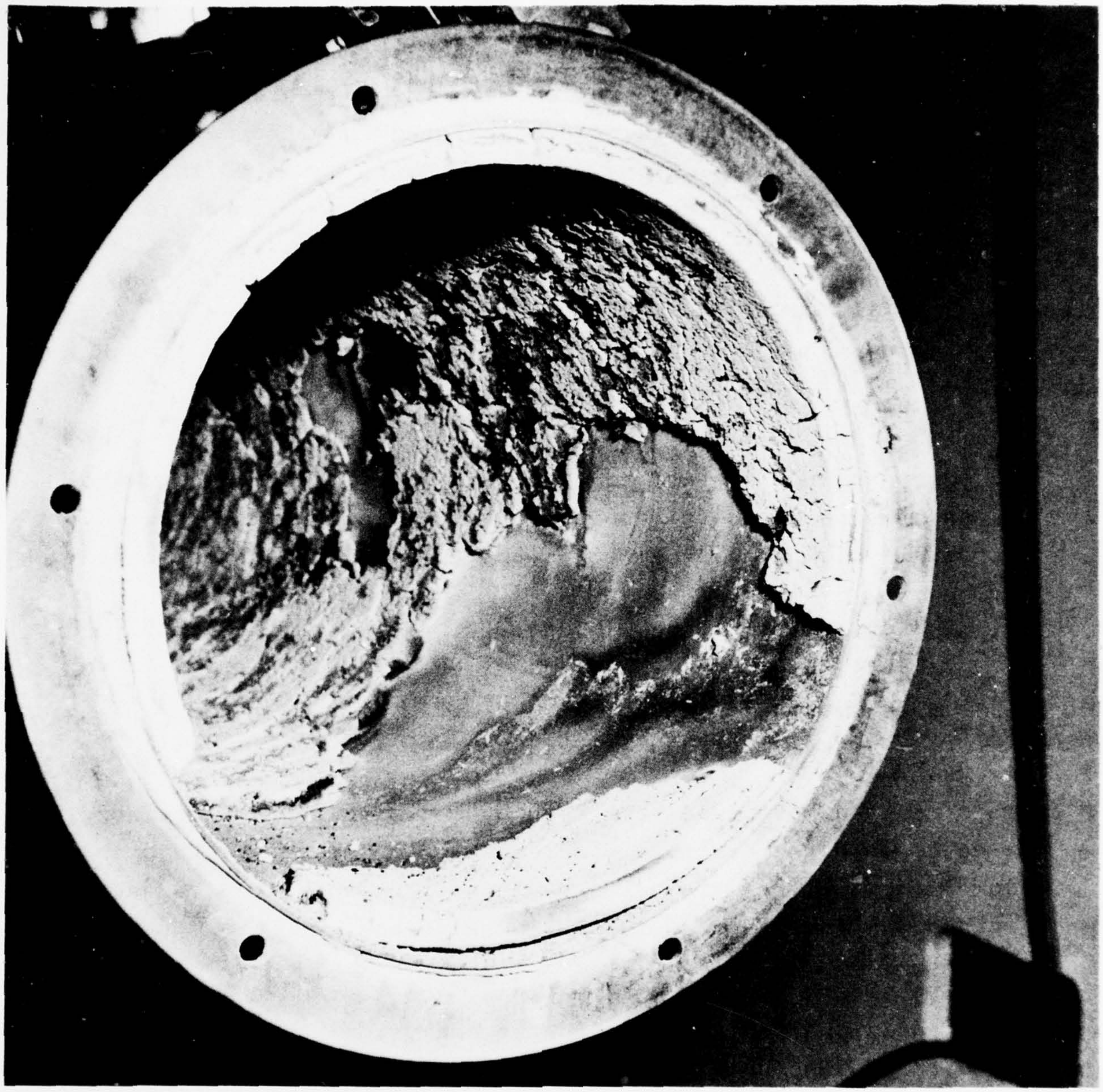


Figure 59. Ablative Coating Damage.

MP-61901

Figure 60. Graphite Nozzle Damage.

MP-61902

After these adjustments were made to the analytical model, performance comparisons were made with engine test data at three conditions, static without the augmentor, ram without the augmentor, and ram with the augmentor. The comparisons are based on those parameters for which measurements are considered to be most accurate. These parameters include engine speed ($N/\sqrt{\theta}_{t2}$), corrected airflow ($W_a\sqrt{\theta}_{t2}/\delta_{t2}$), fuel flow ($W_f$), compressor pressure ratio (P_{t3}/P_{t2}), and exhaust gas pressure (P_{t8}). Engine speed in the analytical model was matched to that of the test engine and the performance model parameters were then compared with the measured test parameters. The following paragraphs discuss these comparisons at the three test conditions.

b. Static Testing

The ETJ131 Model 1030 was installed in AiResearch Test Cell LACC 2 for testing. The initial tests, under ambient conditions for the basic engine checkout, were conducted without the afterburner installed. An engine exhaust nozzle area of 12.24 square inches was used during the static checkout. Table 12 shows a comparison of tested performance versus predicted performance after the adjustments noted above were incorporated in the performance model. Test results at static conditions without the augmentor correlate well with predicted performance. The percentage differences shown for fuel flow and compressor pressure ratio are well within measurement accuracy for those parameters. The differences shown for exhaust gas temperature is not unusual inasmuch as local temperature in a turbine exhaust gas stream will vary widely depending on upstream conditions, such as combustor geometry, pattern factor, turbine geometry, etc.

TABLE 12. ETJ131 MODEL 1030 TEST DATA (AUGMENTOR NOT INSTALLED).

	Test Data	Predicted* Data	% Δ
Net Thrust, Lb	131	131	-
Fuel Flow, Lb/Hr	210	213	-1.40
Corrected Airflow, Lb/Sec	2.78	2.78	-
Compressor Pressure Ratio	3.25	3.28	-0.91
Compressor Discharge Temp °F	362	362	-
Exhaust Gas Temp °F	1547	1605	-3.61
Exhaust Gas Pressure, Psia	20.7	20.7	-

*Model compressor efficiency increased 2.5 points and burner pressure drop increased 2.0 percent

Altitude - 1472 Ft
Ambient Temperature - 74.4°F
$M_N = 0$
Engine Speed - 68314 Rpm

c. Ram Tests

The engine, without augmentor, was subsequently tested at two ram conditions, Mach 0.28 and Mach 0.70. The results of those tests are summarized in Tables 13, 14, and 15. Correlation between the test data and the performance prediction is generally satisfactory for fuel flow, airflow, compressor pressure ratio, and exhaust pressure. However, there is a 7 to 9 percent difference in thrust for the higher ram conditions that is attributable to interference between the inlet labyrinth seal and the inlet duct.

Following installation of the augmentor and augmentor nozzle, Figure 58, approximately 40 minutes of running was completed before an augmentor light-off was attempted. Efforts were made during this period to resolve the error in thrust measurement caused by the labyrinth seal. Performance data was acquired with the augmentor unlit to compare with the Model 1030 engine data without augmentor. Following this testing, an augmentor light-off was successfully made and limited data were acquired while familiarity was gained with the augmentor operation. During this testing, a portion of the augmentor ablation liner separated from the casing. Further testing was precluded because of the time required to refurbish or fabricate a new augmentor.

Of the four test points acquired during the lighted augmentor testing, only one point had complete, stabilized test data. For this data point, it was necessary to incorporate an additional adjustment to the performance prediction model to account for turbine discharge and nozzle flange leakage. It was estimated from physical measurements and data analysis that the effective nozzle area increased 12 to 15 percent due to imperfect sealing between the turbine housing exit flange and the augmentor attachment flange, and to a crack in the thrust

TABLE 13. ETJ131 MODEL 1030 TEST DATA (AUGMENTOR NOT INSTALLED).

	Test Data	Predicted* Data	% Δ
Net Thrust, Lb	77	77	-
Fuel Flow, Lb/Hr	155	161	-3.73
Corrected Airflow, Lb/Sec	2.48	2.47	-0.40
Compressor Pressure Ratio	2.73	2.73	-
Compressor Discharge Temp °F	293	304	-3.62
Exhaust Gas Temp °F	1231	1328	-7.30
Exhaust Gas Pressure, Psia	19.25	19.0	1.32

*Model compressor efficiency increased 2.5 points and combustor pressure drop increased 2.0 percent

Altitude - 1509 Ft
Ambient Temperature - 64.6°F
M_N = 0.282
Engine Speed - 61137 RPM

TABLE 14. ETJ131 MODEL 1030 TEST DATA (AUGMENTOR NOT INSTALLED).

	Test Data	Predicted* Data	% Δ
Net Thrust, Lb	91	98	-7.1
Fuel Flow, Lb/Hr	200	200	-
Corrected Airflow, Lb/Sec	2.81	2.70	4.07
Compressor Pressure Ratio	2.96	2.90	2.1
Compressor Discharge Temp °F	316	318	-0.63
Exhaust Gas Temp °F	1177	1198	-1.75
Exhaust Gas Pressure, Psia	24.42	23.3	4.8

*Model compressor efficiency increased 2.5 points and combustor pressure drop increased 2.0 percent

Altitude - 1439 Ft
Ambient Temperature - 67.9°F
$M_N = 0.678$
Engine Speed - 63895 RPM

TABLE 15. ETJ131 MODEL 1030 TEST DATA (AUGMENTOR NOT INSTALLED).

	Test Data	Predicted* Data	% Δ
Net Thrust, Lb	72	79	-8.9
Fuel Flow, Lb/Hr	171	172	-0.58
Corrected Airflow, Lb/Sec	2.69	2.60	3.46
Compressor Pressure Ratio	2.75	2.70	1.85
Compressor Discharge Temp °F	283	284	-0.35
Exhaust Gas Temp °F	1074	1068	0.56
Exhaust Gas Pressure, Psia	22.47	21.97	2.27

*Compressor efficiency increased 2.5 points and combustor pressure drop increased 2.0 percent

Altitude - 1470 Ft.
Ambient Temperature - 58.2°F
$M_N = 0.68$
Engine Speed - 60652 RPM

nozzle attachment flange. A comparison of tested and predicted data is given in Table 16. Correlation of the most accurately measured values is very good and temperature correlation is also good. The difference in thrust is attributable to interference between the labyrinth seal and the inlet duct.

d. Conclusions

The results of the testing indicate that the thrust goal of 200 pounds at sea-level, Mach 0.7, can be achieved. Demonstration of this goal requires development of the combustor to reduce its pressure loss, re-design of sealing in the turbine exit area, and a modified approach to thrust nozzle attachment.

Testing of the engine without the augmentor validated performance predictions for the basic Model 1030.

The water-cooled augmentor testing demonstrated conclusively that the predicted augmentor efficiency levels can be achieved.

Further development of the ablative liner is required. The total time of 6 minutes at temperature is significantly less than the 30-minute objective. Moreover, the life consumed while operating at non-augmented conditions cannot be quantified. Recent developments in ramjet technology offer attractive means of improving the integrity of the ablative liner.

TABLE 16. ETJ131 MODEL 1030 TEST DATA (AUGMENTOR ON).

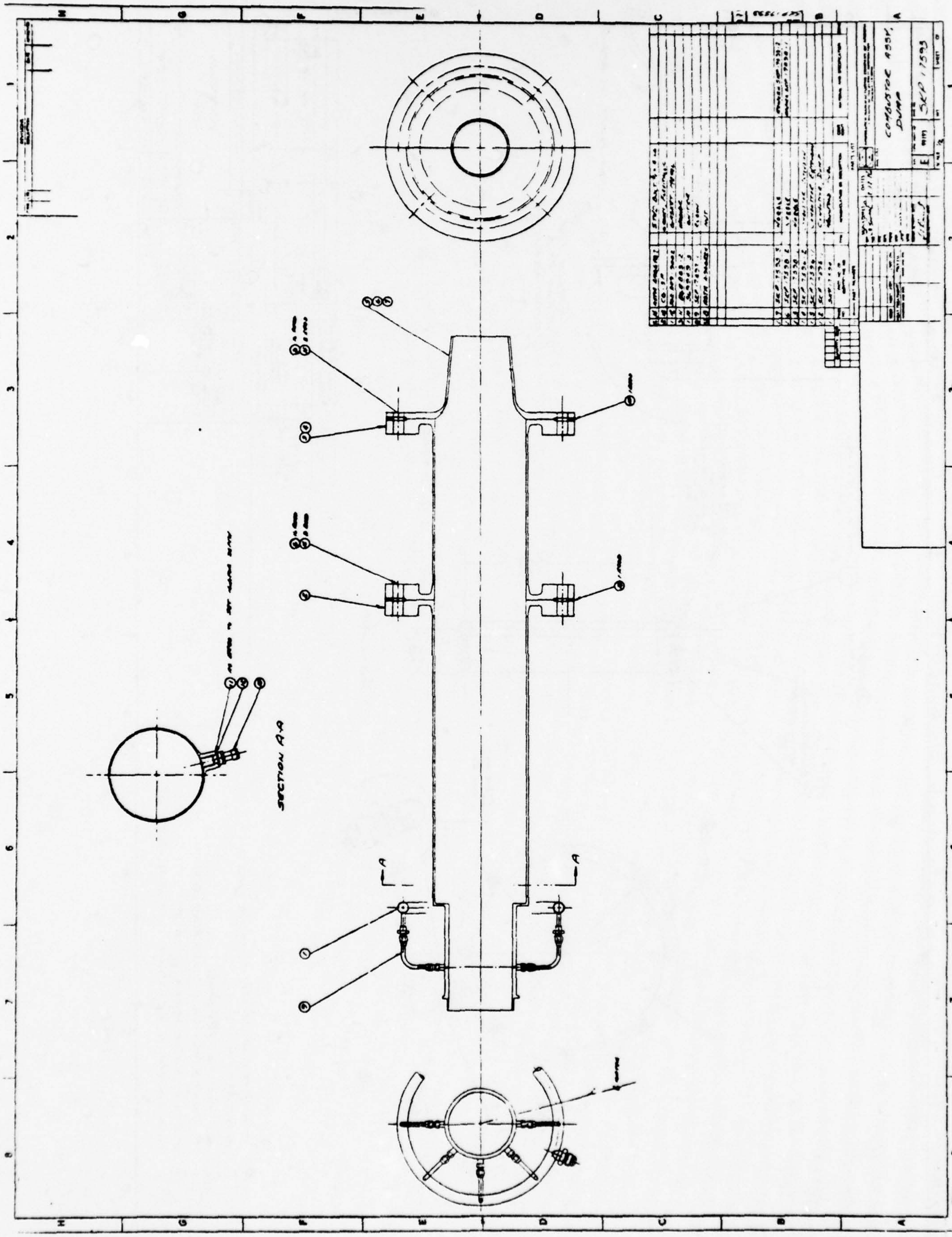
	Test Data	Predicted* Data	% Δ
Net Thrust, Lb	151	174	-13.2
Fuel Flow, Lb/Hr	278	273	1.83
Corrected Airflow, Lb/Sec	2.87	2.90	-1.03
Compressor Pressure Ratio	3.3	3.3	-
Compressor Discharge Temp °F	346	352	-1.70
Exhaust Gas Temp °F	1350	1347	0.22
Exhaust Gas Pressure, Psia	23.86	23.67	0.80

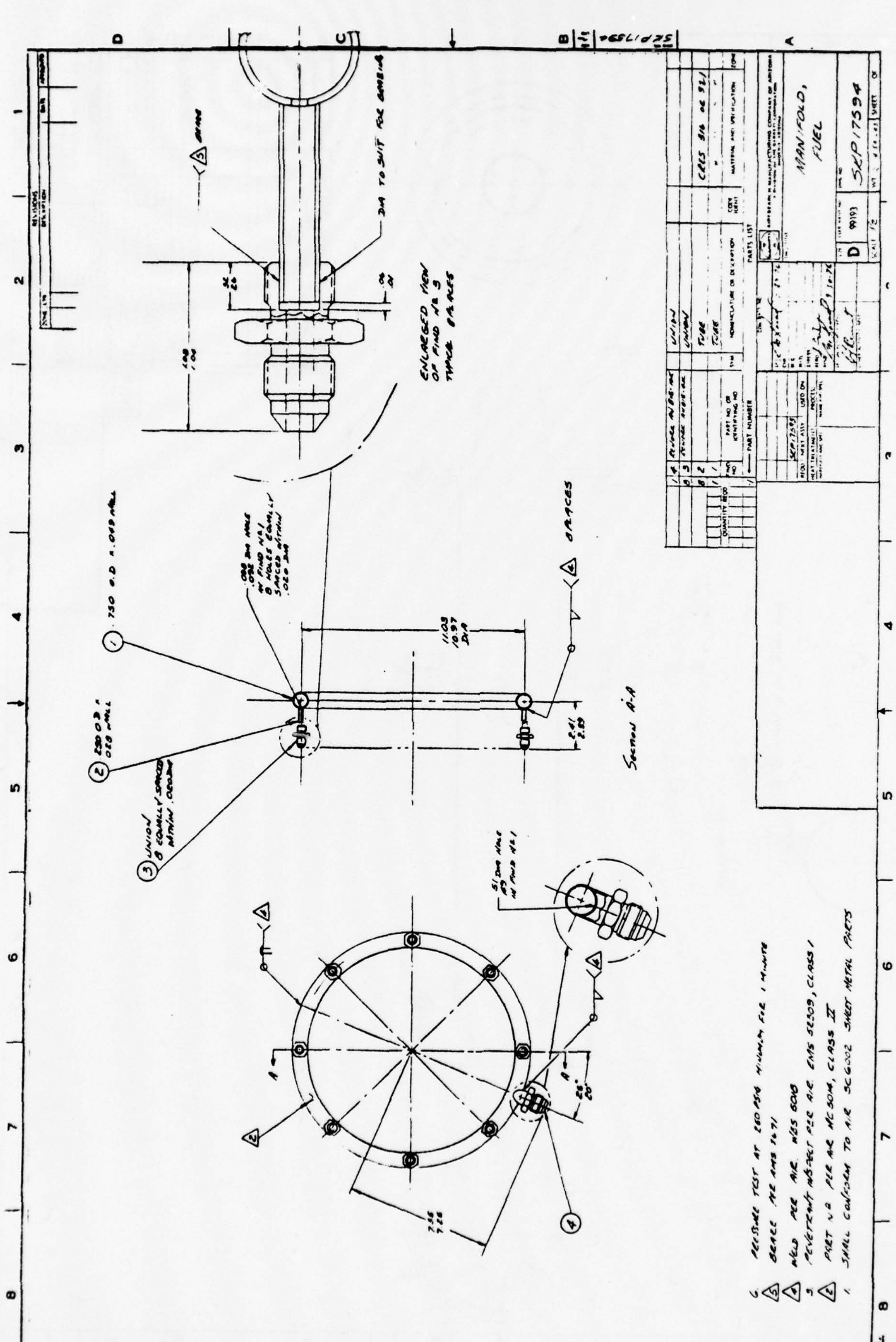
*Model compressor efficiency increased 3.0 points, combustor pressure drop increased 2.0 percent and nozzle area increased 15 percent

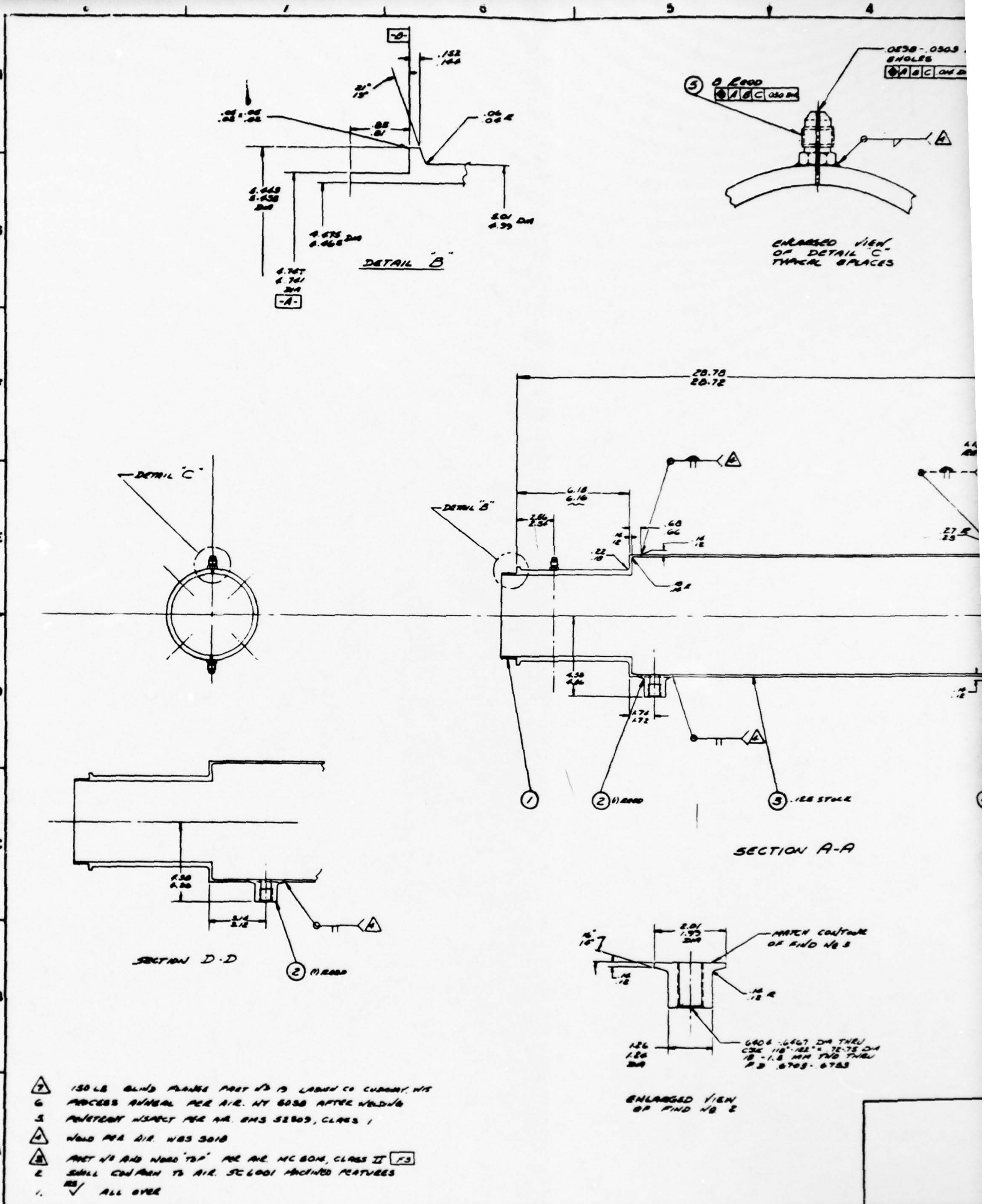
Altitude - 94 Ft
Ambient Temperature - 12.8°F
M_N = 0.7141
Engine Speed - 69096 RPM

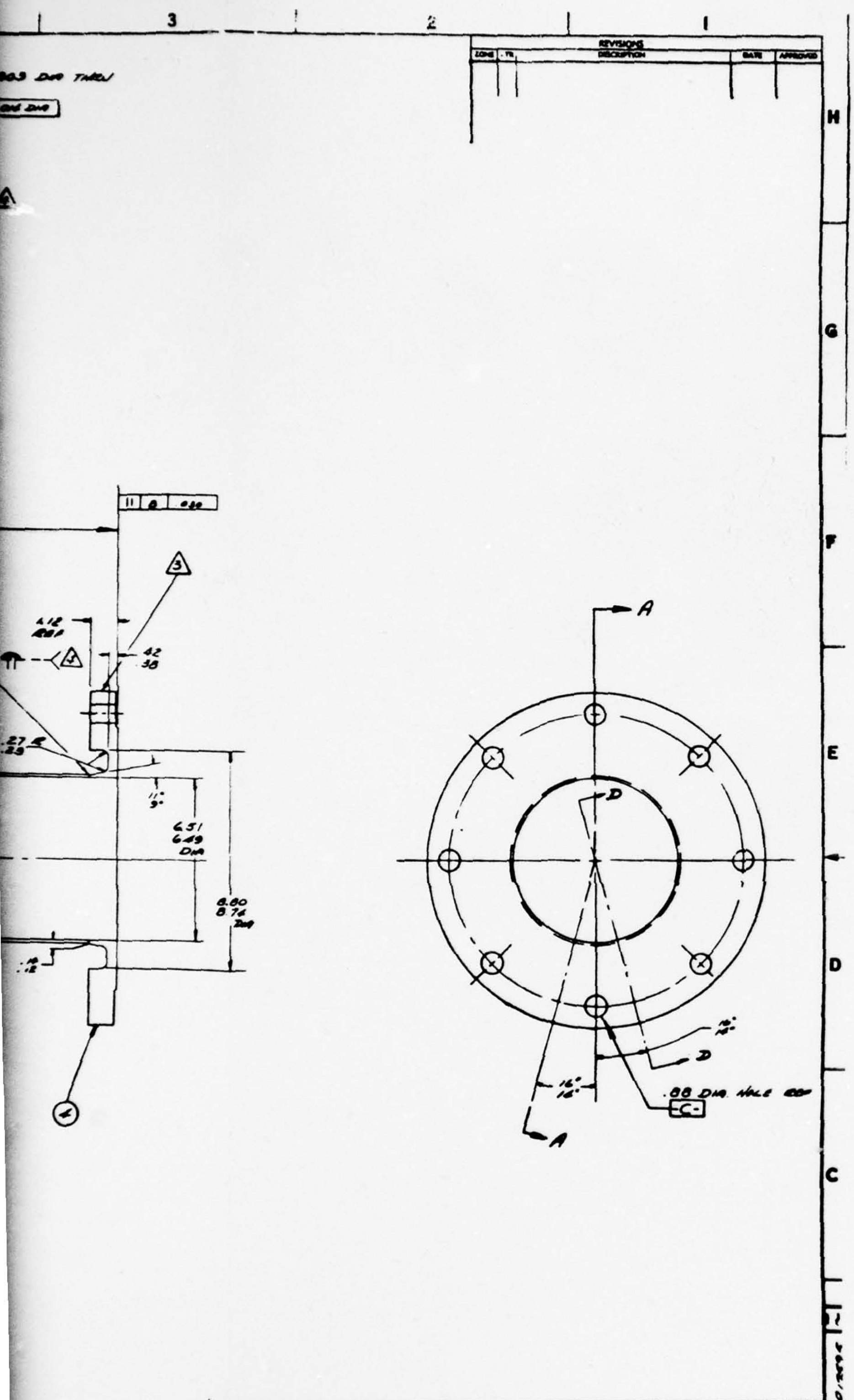
APPENDIX A

DRAWINGS


COMBUSTOR ASSY,
DUMP
SKP 17593
SECTION A-A


MANIFOLD, FUEL
SKP17594
SECTION A-A
ENLARGED VIEW OF FIND NO 3 TYPICAL 8 PLACES
UNION
TUBE
CRES 316 OR 321
PARTS LIST
8 PLACES
SHALL CONFORM TO AIR SC6002 SHEET METAL PARTS


DETAIL "B"
DETAIL "C"
ENLARGED VIEW OF DETAIL "C" TYPICAL 8 PLACES
SECTION A-A
SECTION D-D
ENLARGED VIEW OF FIND NO 2
MATCH CONTOUR OF FIND NO 3
28.78
28.72
6.18
6.16
.125 STOCK
7 150 LB BLIND FLANGE PART NO 13 LADISH CO CUDAHY, WIS
6 PROCESS ANNEAL PER AIR. NY 6030 AFTER WELDING
5 PENETRANT INSPECT PER AIR. EMS 52809, CLASS 1
4 WELD PER AIR. WBS 3010
3 PART NO AND WORD "TOP" PER AIR. MC 80M, CLASS II F3
2 SHALL CONFORM TO AIR. SC 6001 MACHINED FEATURES
1. 125 ALL OVER



QUANTITY REQD	FIND NO	PART NO OR IDENTIFYING NO	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION	ZONE
8	5	AN806-K4		PLUG		8166 REF	
1	4		7	FLANGE		316 CRES	
1	3			TUBE		316 CRES	
2	2			BOSS		316 CRES	
1	1			TUBE		316 CRES	
-1	← PART NUMBER						

PARTS LIST

1(-1)	SKP17573	
QTY REQD	NEXT ASSY	USED ON
HEAT TREATMENT		PROCESS

SIGNATURES DATES 9-27-76 9-30-76

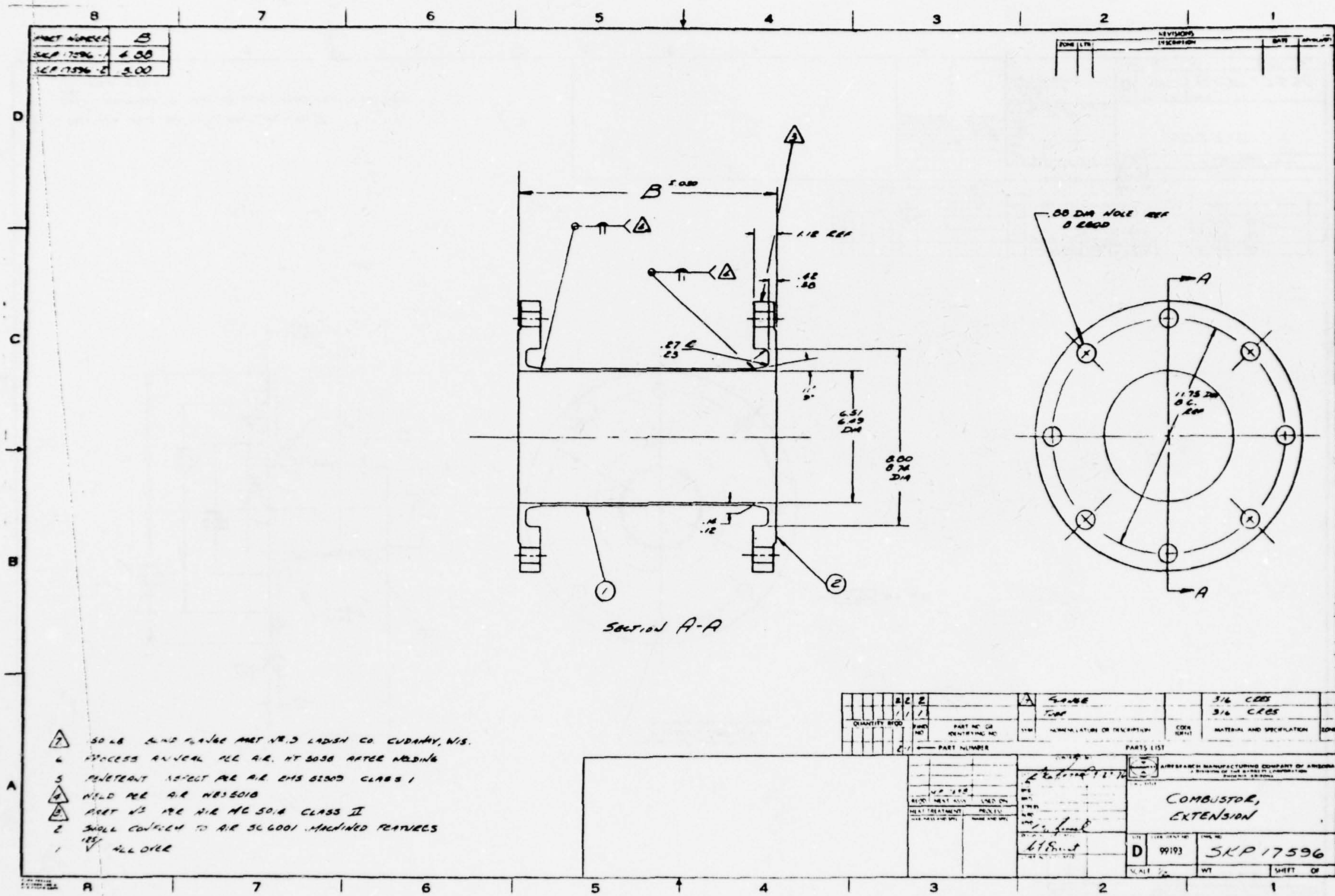
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE: COMBUSTOR, DUMP

SIZE: E | CODE IDENT NO: 99193 | DWG NO: SKP 17535

SCALE | WT. | SHEET OF

2



PART NUMBER | B
SKP 17596-1 | 6.88
SKP 17596-2 | 3.00
REVISIONS
ZONE | LTR | DESCRIPTION | DATE | APPROVED
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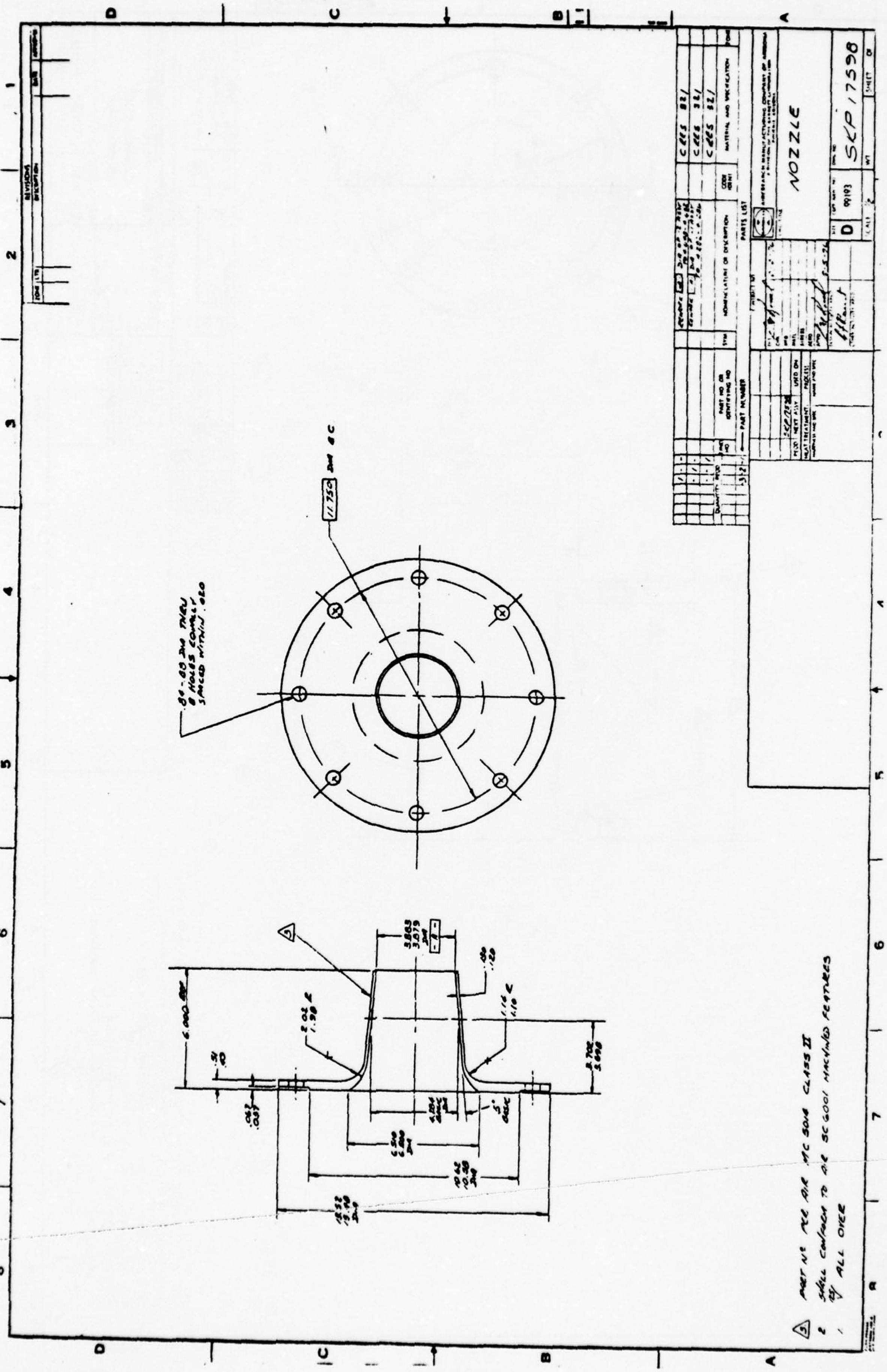
1.12 REF
.42
.38
.27 R
.23
6.51
6.49 DIA
8.00
8.76 DIA
.16
.12
SECTION A-A
.88 DIA HOLE REF
8 REQD
11.75 DIA B.C. REF
A
A
7 50 LB BLIND FLANGE PART NO.3 LADISH CO CUDAHY, WIS.
6 PROCESS ANNEAL PER A.R. HT 3038 AFTER WELDING
5 PENETRANT INSPECT PER A.R. EMS 52303 CLASS I
4 WELD PER A.R. WBS5010
3 PART NO.3 PER A.R. MC 50.6 CLASS II
2 SHALL CONFORM TO A.R. SC 6001 MACHINED FEATURES
1 125 ALL OVER
2 FLANGE 316 CRES
1 TUBE 316 CRES
QUANTITY REQD
PART OR IDENTIFYING NO
NOMENCLATURE OR DESCRIPTION
MATERIAL AND SPECIFICATION
PARTS LIST
PART NUMBER
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
COMBUSTOR, EXTENSION
D 99193 SKP 17596
SCALE 1/2
SHEET OF



NOZZLE
SKP17598
PARTS LIST
MATERIAL AND SPECIFICATION
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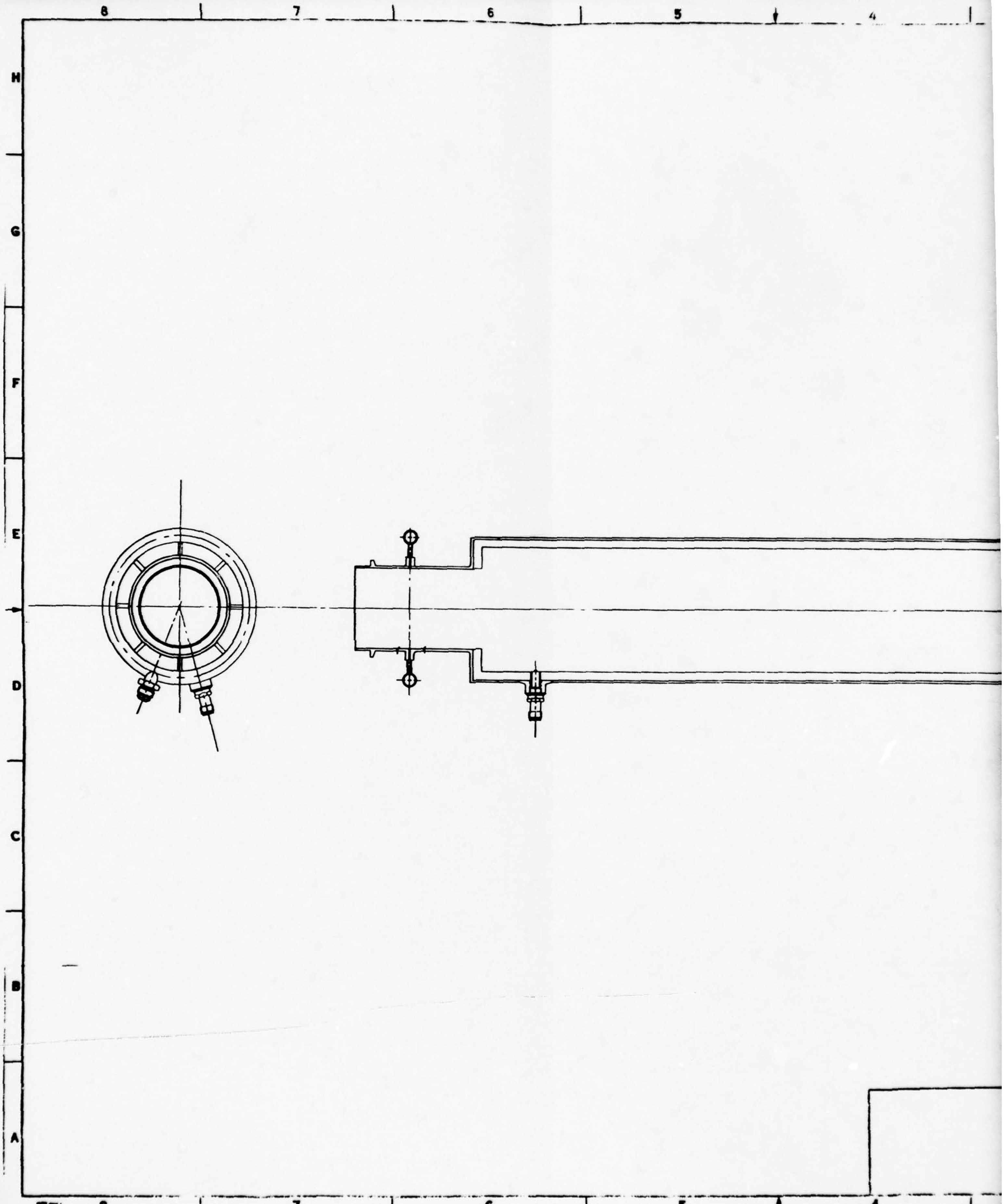
11.750 DIA BC
.81-.83 DIA THRU
8 HOLES EQUALLY
SPACED WITHIN .020
PART NO PER AIR MC 5016 CLASS II
SHALL CONFORM TO AIR SC 6001 MACHINED FEATURES
ALL OVER



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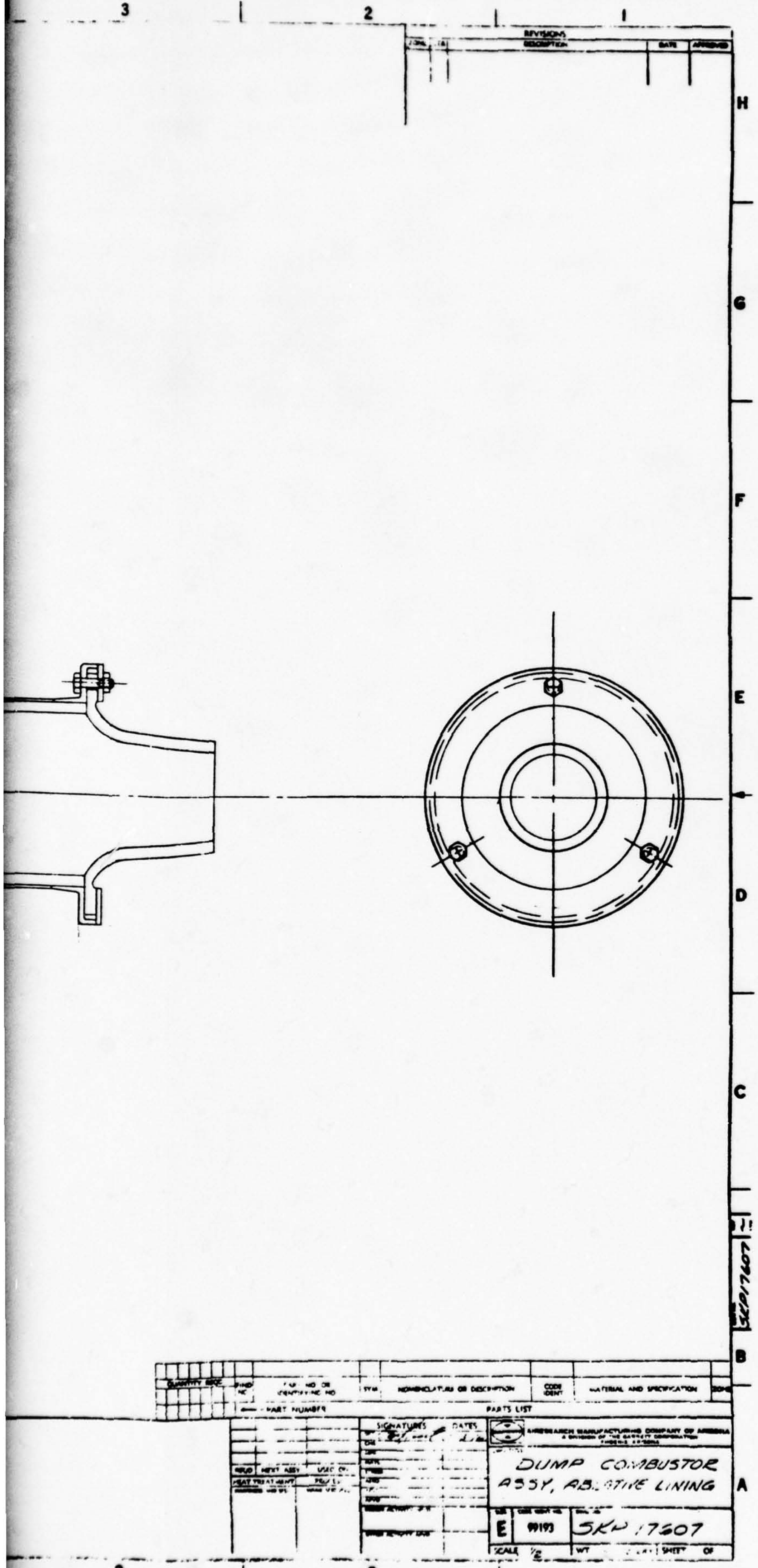
REVISIONS
DESCRIPTION
DATE
APPROVED
NOMENCLATURE OR DESCRIPTION
CODE IDENT
MATERIAL AND SPECIFICATION
PART NUMBER
PARTS LIST
SIGNATURES
DATES
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
DUMP COMBUSTOR
ASSY, ABLATIVE LINING
E
99193
SKP 17607
SCALE
SHEET
OF

2

APPENDIX B

QUALIFICATION TEST DATA

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-779320-36-0100	Date 11-30-77	Test Cell or Station No. Lab #2
Assembly No.	Model No. EAT 131	Unit Serial No.
Development Engineer Ken Clark	Technician Steve J. Bailey	Grp. Ldr. Jack Bennett
Test Type	Test Schedule	Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
					Unit installed in test fixture.
					instrumentated per Eng. Request.
					Unit oil Reservoir serviced with
					Mil-23699 oil.
					Unit fuel system supplied
					with Jet Kero.
					Swings Arreola/Fricke
					Cell and Unit ck. List Completed
1800	—				R/O to 6K Prime oil. 80PPM Fuel Bypass
1802			1		L/O to Blow out. Relite. Spd to 47263
					15PSI oilPress, 87PPM Fuel, Lost spd. on Anadex
					TOOK 5 SCANS
					oilPress dn. to 10PSI Increased Reg. Air to 90 PSI
					oil Back to 15 PSI gage.
					TOOK 5 SCANS
					Increased Fuel Flow to 98 PPM, Spd 50192
					t_4 1100°F, t_5 930°F
					TOOK 5 SCANS

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGINAL

FORM NO. P6350 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona Page No. 2 of 15

QUALIFICATION TEST LOG

E.W.O. No. 3209-779320-36-D100	Date 11-30-77	Test Cell or Station No. CACC #2
Assembly No.	Model No. ETJ 131	Unit Serial No.
Development Engineer	Technician Arreola/Fricke	Grp. Ldr. J Bennett
Test Type	Test Schedule	Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
					Unit Flow to 76 PPM for Cool dn.
	1820	:17 / :17			Fuel shut down.
					No THRUST OR SPEED ON Doric/Antdex
					During THIS Run.
					Recentered Laby. to Plenum area.
1859	-				R/O 79 PPH Fuel Flow.
1900			2		L/O to Blow out Reduced Bypass to
					60 PPH Flow. L/O to 38,381, 800°T5, 895° T4
					100 PPH Flow; 41083, 947°F T5, 1100° T4
					150 PPH Flow; RPM ERRATIC, 985°F T5, 1210° T4
					100 PPH Flow; RPM ERRATIC, 950°F T5, 1090° T4
					Reduced Flow to 80 PPH for cool dn.
	1955	:55 / 1:12			shut down.
					Moved Plenum out of Labyr. 1/4" Approx
					Due to Rub.
2112			3		R/O to L/O 90 PPH 900° T5, 1130° T4,

SUMMARY: Total Running Time ____ hrs. ____ min.
Total Manual Starts ____
Total Automatic Starts ____

Ref. Data Page ____

Engineering ____

ORIGINAL

FORM NO. P8330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-777.320-36-0100 | Date 11-30-77 | Test Cell or Station No. CACC #2

Assembly No. | Model No. ETJ 131 | Unit Serial No.

Development Engineer R Clarke | Technician Arredondo/Pierce | Grp. Ldr. J Bennett

Test Type | Test Schedule | Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		1:12	3		
					SPEED 47775 RPm.
					101 PPH 900° T5, 1130° T4, 50211 RPM
					150 PPH 1060 T5, 1340 T4, 60250 RPM
					90 PPH 899° T5, 1023 T4, 47377 RPM
	2122	:10 1:22			Shut down to move plenum.
					Plenum Moved Away from Eng. Approx
					2-3"
2127			4		R/o to 4c. 90 PPH, 1050°T5, 1088°T4, 46780 RPM
					100 PPH 1130°T5, 1265°T4, 50268 RPM
					150 PPH 1420 T5, 1668 T4, 61785 RPM
					200 PPH 1690 T5, 1930 T4, 69407 RPM
					Oil Press Air Increased to 100 PSI on
					Reg. Oil Press Had dropped to 9 PSI
					Reduced speed and Fuel to 80 PPH
	2149	22 1:44			& for Cool. Shut Unit down

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______

Total Manual Starts ______

Total Automatic Starts ______ Engineering ______

ORIGINAL

FORM NO. P8330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-77320-36-0100 | Date 12-2-77 | Test Cell or Station No. 6a - #7

Assembly No. ____ | Model No. EAT 121 | Unit Serial No. ____

Development Engineer R. Clark | Technician Williams Bailey | Grp. Ldr. Jack Bennett

Test Type ____ | Test Schedule ____ | Modification ____

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		1:44			
					Removed Plenum & installed Bell Mouth
					Directly to Comp inlet.
1222					S/O Accel to 50,000
					Set up 98.1# Fuel Flow 70% spd.
					Record Dig Data
					Set up 90% spd Fuel Flow
					T4 temp # 2 High = 2100°F
	1241	:19 2:03			Manual shut Down.
					Change P bar meter No. from
					11 to 100 on Bennett Calculate
					Data.
					Repair termocuple on T4.
1447					S/O to 70%
					Dig Data Recorded 3 scans
					increase spd to 57,300
					Dig Data Recorded. 3 scans
					increase spd to 63,000
					Dig Data Recorded. 3 scans
					increase spd to 65,500
					Dig Data Recorded. 3 scans
	1513	:28 1:31			Manual shut Down.

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGI!

FORM NO. PS330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-TT9320-36-0100 Date 12-5-77 Test Cell or Station No. CACC#2

Assembly No. Model No. ETJ 131 Unit Serial No.

Development Engineer R. Clarke Technician Arreola/Fricke Grp. Ldr. J Bennett

Test Type Test Schedule Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		1:31			
					Load cell Calib Completed by Days.
					Bellmouth, Exhaust, Combustor Inst by swings.
					Zero off set ~~[illegible]~~ CALIB completed
					Cell and Unit CK. List Completed, Sanborn Calib completed.
					Roll over oil Prime, 90 PPH ByPass
1938			7		40 to 48400 RPM T5 1080°, T4 1477°
					5 SCANS TAKEN
					58500 RPM T5 1340°, T4 1880° 137 PPH
					5 SCANS TAKEN
					Reduce Flow to 80 PPH for Shut down.
	2002	:24 1:55			MANUAL Shut down.
					Swings 12-6-77 Arreola/Fricke
					cell and unit CK List Completed
					off set Calib Done Sanborn Calib Compl.
					R/O for oil Prime @ 6000 RPM
1759			8		L/O to 49500 RPM 90 PPH Fuel.
					5 SCANS TAKEN

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____

Total Manual Starts ____

Total Automatic Starts ____ Engineering ____

ORIGINAL

FORM NO. PS330 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-779320-36-0100 Date 12-6-77 Test Cell or Station No. LACC #2

Assembly No. ______ Model No. ETJ 131 Unit Serial No. ______

Development Engineer R Clarke Technician Arreola/Fricke Grp. Ldr. Bennett

Test Type ______ Test Schedule ______ Modification ______

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		1:55	8		
					to 61000 RPm 155 PPH 1350°T5, 1580°T4
					5 SCANS TAKEN
					TO 68800 212 PPH 1580°T5, 1940 T4
					5 SCANS TAKEN
					Reduced speed to 47200 92 PPH Fuel to
					cool dn Unit
					5 SCANS TAKEN
	1826	:27 2:22			MANUAL SHUT DOWN
					Bell mouth Removed for orig.
					Configuration in Air Plenum.
					Air Plenum Config. setup by
					Days.
					Swings 7 Dec 77 Arreola/Fricke
					Digit. off Cal. compl. Sanborn Calib
					Completed. Check Lists Completed
					R/O @ 6000 RPm 90 PPH oil Prime
2108			9		40 to 50000 RPm. Reduced Spd. to
					46000 RPm, 1035 T5, 1480 T4, 90 PPH

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______
Total Manual Starts ______
Total Automatic Starts ______ Engineering ______

ORIGINAL

FORM NO. PE330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-779,320-36-0100 Date 12-7-77 Test Cell or Station No. LACC #2

Assembly No. Model No. ETJ 131 Unit Serial No.

Development Engineer R. Clarke Technician Arredola/Fricke Grp. Ldr. J Bennett

Test Type Test Schedule Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
2108		2:22	9		
					to 62,000 172 PPH, 1215°T5, 1815°T4
					5 SCANS
					Increased Ram to 150" ~~Ram~~ WATER
					60000 RPM 164 PPH 1050°T5, 1350°T4
					Increased Fuel Press on Reg to 200 Lbs.
					Fuel Press on Recorder was 108 PSI.
					64,300 RPM 203 PPH 1180°T5, 1600°T4
					150" H_2O, oil temp 190°F
					5 SCANS TAKEN
					Reduced Ram and Speed.
					Ram 12", Fuel 90 PPH, 47,000 RPM
					5 SCANS TAKEN
					Ram 12" Spd to 48000, 94 PPH, 1070°T5
					1570°T4 5 SCANS TAKEN
					Increase Fuel to 162 PPH. 12" H_2O RAM
					RPM 61,000, 1260°T5, 1850°T4,
					5 SCANS taken
					Increased Fuel Reg. to 200, Unable
					to get Above 65,500 RPM, 208 PPH.
					Reduced Spd to 48000 for Cool dn.
	2154	:46 3:08			MANUAL Shut down.

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGINAL

FORM NO. PE530 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No.	Date 12-7-77	Test Cell or Station No. LACC II
Assembly No.	Model No. ETJ-131	Unit Serial No.
Development Engineer RON CLARKE	Technician ARREOLA/FRICKE	Grp. Ldr. J Bennett
Test Type	Test Schedule	Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		308	9		
					PREVIOUS RUN WAS REQUESTED
					BY RON CLARKE OF PROJECT
					ENGINEERING EVEN THOUGH
					SET UP WAS NOT COMPLETED.
					12-7-77 Bill Fricke
					12-8-77 Swings Arreola/Fricke
					Cell and Unit Calib. Completed
					Digit. off CAL, Sanborn Calib Compl
					R/O to 6K. 90 PPH fuel oil Prime
1837			10		L/O to 46900 - Wf to 110 PPH - Reduced
					to 90 PPH. Spd to 47700 RPM.
					5 SCANS TAKEN
					Increased Ram to ? Unit Blew out
					Reduced Spd to 6K. for Relite; Completed.
					Increased Ram to 150" H2O 60K Spd.
					172 PPH Fuel 1050° T5 1200° T4
					5 SCANS TAKEN

SUMMARY: Total Running Time ______ hrs. ______ min.
Total Manual Starts ______
Total Automatic Starts ______

Ref. Data Page ______
Engineering ______

ORIGINAL

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. ____ Date ____ Test Cell or Station No. ____

Assembly No. ____ Model No. ____ Unit Serial No. ____

Development Engineer ____ Technician ____ Grp. Ldr. ____

Test Type ____ Test Schedule ____ Modification ____

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		3:08	T/D		
					Increased RPM to 68,000 when
					Fire eruptedin cell. shut off all
	1855	3:24 16			Fuel. Tank to 45 K ALT. for Burn out
					Found Turbine wheel Had Failed
					AT SHAFT HUB
					UNIT REMOVED AND FOLLOWING
					HARDWARE REPLACED:
					• TURBINE HOUSING
					• CENTER BODY, BEARINGS, SEALS, ETC
					• TURBINE WHEEL & IMPELLER
					UNIT REASSEMBLED AND RE
					INSTALLED WITH AFTER BURNER
					Unit installed in Test Fixture.
					Instrumented Per Eng. Request
					Unit oil Reservoir Serviced with
					mil 23699 oil.
					Fuel System Supplied with Ave. Kero

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGINAL

FORM NO. PE330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3209-779320-36-0100 Date 12-13-77 Test Cell or Station No. LACC #2

Assembly No. ____ Model No. GTS131 Unit Serial No. ____

Development Engineer R Clarke Technician [illegible] Grp. Ldr. Jack Barnett

Test Type ____ Test Schedule ____ Modification ____

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		3:24	10		
					Roll over to 6K for oil Prime
1901			11		L/O to 50,300 RPM, T4 1033°F 108 PPH
					Fuel Flow.
					Increase Flow to 55K Blow out
					And Re-Lite.
					MAINTAIN RPM @ 55K. TO IN-
					CREASE Ram to 150" H2O.
					Unit Began to Torch out Exh.
					nozzle.
	1906	3:29 (05)			MANUAL Shut down.
					Inspection of Unit Revieled leading
					edge of Turbine wheel Burnt off.
					Unit Removed From Facility for Repair

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGINAL

FORM NO. PS330 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3409-245847-50-0300 Date 12-15-77 Test Cell or Station No. LACC #2

Assembly No. ______ Model No. ETJ 131 Unit Serial No. ______

Development Engineer Ron Clarke Technician Arredla/Fricke Grp. Ldr. Jack Bennett

Test Type ______ Test Schedule ______ Modification ______

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
					REMOVED ENGINE, DISASSEMBLED
					AND REPLACED FOLLOWING
					PARTS;
					o CENTER BODY, BRGS, ETC.
					o IMPELLER
					o COMP BACK PLATE
					o TURBINE WHEEL
					ADDED T5 & PT5 INSTR
					Unit Re-INSTALLED in TEST Facility
					Instrumented Per Engr. Instructions
					Unit oil Reservior serviced with mil.23699
					oil.
					Fuel System Supplied with Av. Kero
					Digital off Cal. Completed, Sanborn
					Recorder Calib.
					Facility CHECK List Completed.

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______
Total Manual Starts ______
Total Automatic Starts ______ Engineering ______

ORIGINAL

FORM NO. PS330 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3409-145847-50-0300	Date 12-15-77	Test Cell or Station No. LACC #2
Assembly No.	Model No. ETJ 131	Unit Serial No.
Development Engineer Ron Clarke	Technician Arreola/Chicke	Grp. Ldr. Jack Bennett
Test Type	Test Schedule	Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
					R/O to 40K and oil Prime - No speed Read out.
					Removed Bellmouth Assy to ZAP (magnitize) Compressor Nut.
					ReInst. Labryinth Seal and Bell mouth.
			—		12-16-77 ZERO OFFSET + CALIB COMPLETED
					CHK LIST COMPLETED
					R/O + L/O - HIT O'TEMP + SHUTDOWN
					R/O + L/O - " " "
0930			1		L/O + ACCEL TO 52000, 104 PPH - TAKE DIGITAL SCANS
	0933	:03 :03			+ SHUTDOWN + CHK DATA/INSTR.
					CHK LIST COMPLETED
1305			2		L/O + ACCEL TO 50000 100 PPH + INCR SPD TO
	1315	10 13			60000 - + TAKE DATA, DECR TO 50000 +
					SHUTDOWN
1405			3		L/O + ACCEL TO 52000 - INCR SPD SLOWLY TO
	1414	09 22			67000 + TAKE DATA, DECR TO 50000 + SHUTDOWN

SUMMARY: Total Running Time ______ hrs. ______ min.
Total Manual Starts ______
Total Automatic Starts ______

Ref. Data Page ______

Engineering ______

FORM NO. P5330 A
STANDARD FORMS CO. PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. 3404-245847-50-0300 | Date 12-19-77 | Test Cell or Station No. LACC-2

Assembly No. | Model No. ETJ-131 | Unit Serial No.

Development Engineer RON CLARKE | Technician STEWART-WHITTEN | Grp. Ldr. JACK BENNETT

Test Type DEV | Test Schedule | Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
		:22	3		
					CHK LIST COMPLETED
1455	—		—		MOTOR @ 10,000 RPM, 114 PPH NO L/O -
					" " 6.000 RPM 100 PPH NO L/O
					CELL ELECT PROBLEM -
					12-20-77
1006			4		MOTOR @ 10000, 105 PPH L/O TO 60,000 RPM
					INCR SPD TO 67000 RPM - BLEW OUT?/SHUTDOWN?
					ON HIGH TOT - MOTOR @ 10,000 + RELIGHT
					INCR TO 60,000 + 180 PPH, UNABLE TO HOLD SPD
	1011	:27	5		INCR FUEL FLOW TO 280 PPH @ 55-60000 RPM -
					- ABORT
					Swings Arreola/Fricke 12-20-77
					Unit and Cell Check List Completed
1634			5		motor Unit to 10K spd. 106 PPH Fuel, L/O to
					54,400. Unit Blew out/Relite Completed
					with Increase of F/F. Increased
					F/F to 125 PPH, Spd to 55 K. Increase
					F/F but Spd. began to become Un-Stable
					from 55K down to 38K, back to 44 K, L/g

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______

Total Manual Starts ______

Total Automatic Starts ______ Engineering ______

FORM NO. PS330 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. ______ Date 12-20-77 Test Cell or Station No. LACC#2

Assembly No. ______ Model No. ETJ-131 Unit Serial No. ______

Development Engineer R. CLARKE Technician [illegible] Grp. Ldr. Jack Bennett

Test Type ______ Test Schedule ______ Modification ______

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
			5		
					to 53K. Shut off Fuel to Unit,
	1637	04 :31			MANUAL Shut down.
					Possible Impeller slipping on
					Turbine shaft.
					Bellmouth Removed for Compressor
				12-21-77	Inspection. RETORQUED IMPELLER
					NUT TO 140 FT-LB AFTER RE-
					SEATING IMPELLER
					CHK LIST COMPLETED
1532	1535	6 :37	6		MOTOR & L/O TO 57000 RPM INCR TO 67000
					DECR TO 50000 & SHUTDOWN-
					MOTOR ENGINE TO 6000RPM L/O ACCEL TO
					53000 RPM. INCREASE RAM TO M=.75 148" H2O
					SPD TO 67,000RPM. BY PASS FLOW TO AB @212#/HR
					L/O AFTER BURNER INCREASE A.B FUEL FLOW
					TO 280#/HR 108# THRUST. TOOK DIGITAL
					SCAN'S SHUTDOWN AFTERBURNER REDUCING
					SPD TO 50,000RPM WITH 14" H2O RAM SHUT DOWN.

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______
Total Manual Starts ______
Total Automatic Starts ______ Engineering ______

FORM NO. P2330 A
STANDARD FORMS CO., PHOENIX

AiResearch Manufacturing Company of Arizona

QUALIFICATION TEST LOG

E.W.O. No. | Date 12-23-77 | Test Cell or Station No. LHCC-2

Assembly No. | Model No. ETJ-131 | Unit Serial No.

Development Engineer R. CLARKE | Technician ULLICH-WHITTEN | Grp. Ldr. BENNETT

Test Type DEV | Test Schedule | Modification

START TIME	STOP TIME	RUN MIN.	STARTS	TIME	REMARKS
			7		
					INST OIL HEX & COMPLETE CHK LIST
0950			8		MOTOR + L/O TO 60,000 - INCR TO 69000
	0958	08			UNABLE TO L/O AFTERBURNER - DECR SPD TO
					60 000 + SHUTDOWN
					REPLACE BAD A/B IGNITOR
1018			9		MOTOR + L/O TO 60 000 INCR TO 67000
	1025	07			UNABLE TO L/O A/B - DECR TO 60,000 +
					SHUTDOWN
					CHK FUEL NOZZLES
1118			10		MOTOR + L/O TO 6000 INCR TO 70000
	1128	10			L/O A/B - TAKE DIGITAL DATA - BURN
					THROUGH ON A/B CAN - ABORT

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____

Total Manual Starts ____

Total Automatic Starts ____ Engineering ____

APPENDIX C

LOAD STAND ANALYSIS
AIRESEARCH DOCUMENT 22-0492

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

LOAD PATH ANALYSIS FOR AIRESEARCH MODEL ETJ131 THRUST STAND

22-0492 December 9, 1977

SUMMARY

The load path analysis outlined in this report was accomplished to determine why the load cell in the ETJ131 test stand does not accurately measure the applied thrust. Structural testing was also conducted to determine the relative stiffnesses of the flexure beams which support the thrust frame to which the engine is mounted.

RECOMMENDATIONS AND CONCLUSIONS

1. The load cell will measure 81.5 percent of the applied thrust. The remaining thrust is reacted by the four flexural beams which support the thrust frame.

2. Accurate and repeatable thrust measurement is possible by calibrating the load cell output to agree with a dead-weight load applied at the engine centerline.

3. Analysis predicts that 87 percent of an axial load applied to the thrust frame along the centerline of the engine, will be measured by the load cell.

4. Test results indicate that 81 percent of an axial load applied to the thrust frame along the centerline of the engine, will be measured by the load cell.

5. The agreement between analytic and test results is close enough to conclude that the engine thrust not sensed by the load cell is being absorbed by the four flexure beams. The test result is of course considered to be the more reliable of the two results.

6. The difference between the analytic and test results is possibly due to lack of 100 percent fixity at the upper end of the member that supports the load cell.

DISCUSSION

Analysis of the thrust stand structure was accomplished with program STRESS. The structural model used for the analysis is shown in Figure 1. The program allows the use of either pinned joints or totally fixed joints. Since the vertical member which supports the load cell is attached to a solid block which is in turn mounted to the upper crossmember by means of two "U" bolts which fit around the block and crossmember, it is doubtful that 100 percent end fixity acutally exists.

Five load cases were investigated. One case consisted of a 200 lb forward load acting along the engine centerline (Point 3 in Figure 1), while the other four cases consisted of a 200 lb load applied to a corner of the frame (Points 1, 2, 4 and 5 in Figure 1). The last four cases were also accomplished by adding dead weights to the actual test stand frame. A tabulation of test versus analytic prediction of load cell readings is shown in Figure 1. The difference between predicted and test data is attributed to lack of 100 percent end fixity at the upper end of the load cell support member. The difference between analysis and test results was then applied to the predicted reading due to engine thrust to determine that the load cell would sense 163 lb for 200 lb of applied thrust.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

In order to measure engine thrust directly from the load cell output without special calibration, it would be necessary to provide pinned joint beams in place of the existing flexure beams.

A. P. Lane
A. Lane
Mechanical Component Design
Engineering Sciences

Approved: D. J. Tree

LOAD POINT	LOAD (LB)	LOAD CELL READING	
		PREDICTED (LB)	MEASURED (LB)
1	200	174	162
2	200	170	154
3	200	175	———
4	200	170	154
5	200	174	162

PREDICTED VS MEASURED LOAD CELL READING FOR A LOAD APPLIED PARALLEL TO ENGINE CENTERLINE

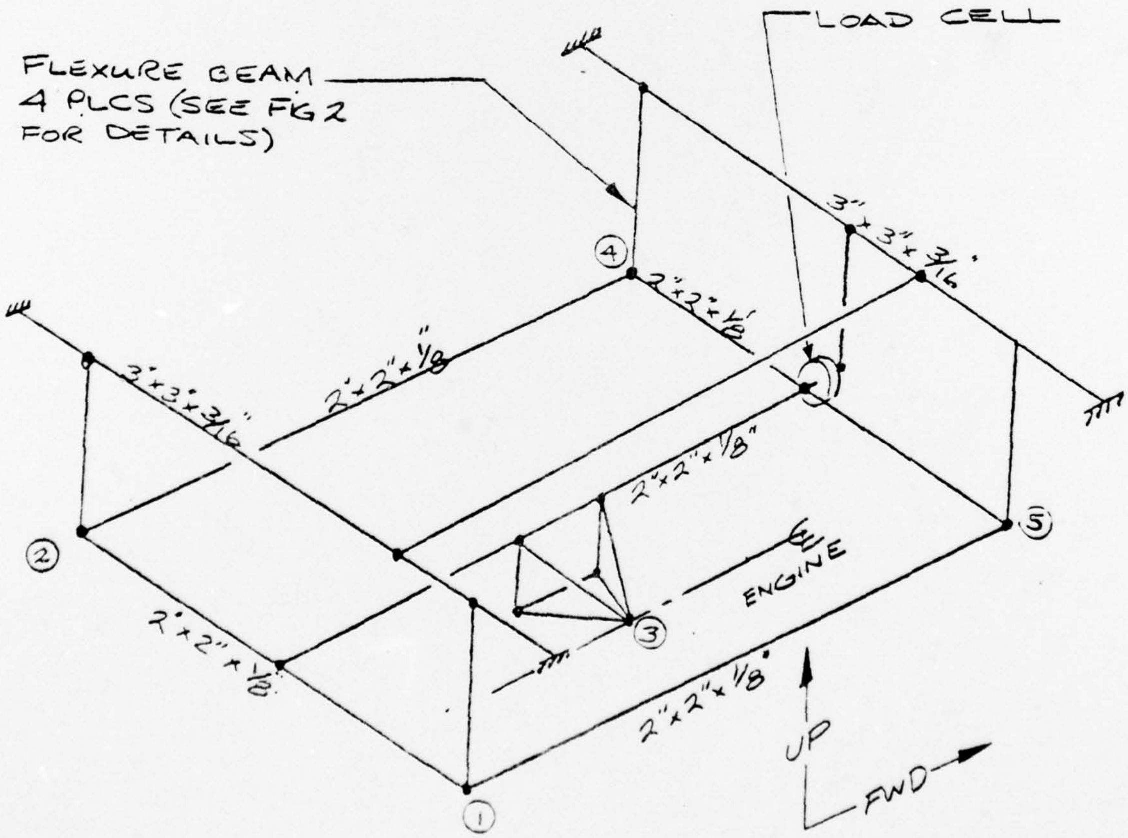

FIGURE 1

ETJ 131 THRUST FRAME - STRUCTURAL SCHEMATIC

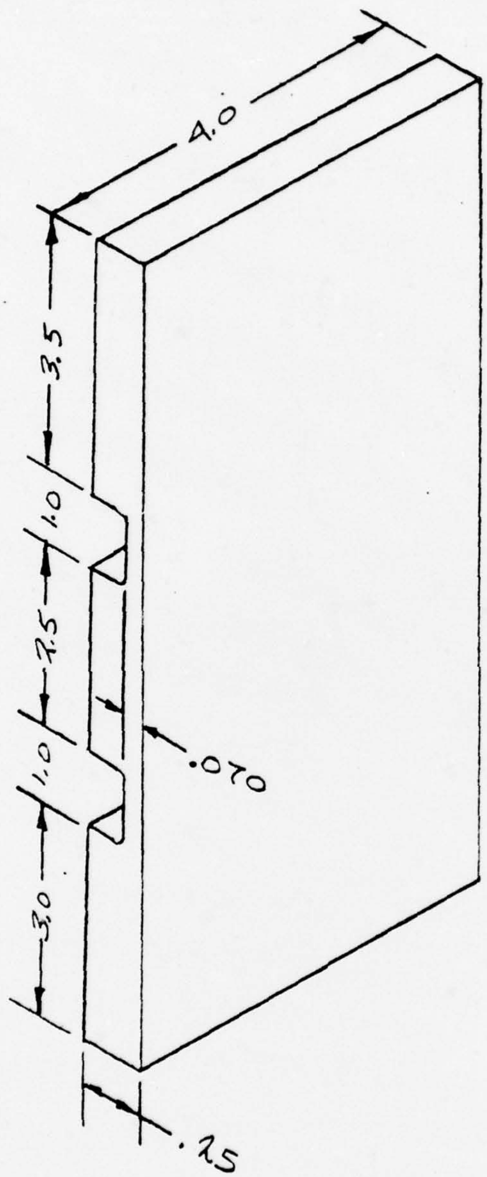

FIGURE 2

ETJ131 THRUST STAND-FLEXURE BEAM DIMENSIONS

APPENDIX D

DEVELOPMENT TEST RESULTS
ETJ131

TABLE 1. DEVELOPMENT TEST RESULTS.

Date	Purpose	Configuration: Exhaust Nozzle Area Sq. In.	Configuration: Fuel Jet Dia. Inch	Configuration: Burner	Fuel Flow (pph): Eng.	Fuel Flow (pph): D/B	Thrust Lbs	T_{T5} Average °F	Run Time Minutes	Remarks
2-15	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	170	-	75	-	21	1st with P_{T8} rake failed comp dischg hose
2-16	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	170	-	82	-	20	Exhaust gas recirc. failed 2 hose clamps
2-16	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	166	-	73	-	21	
2-17	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	-	-	-	-	3	turb inlet leaks, removed turb hsg
2-21	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	175	-	90	1397	8	New turbine housing
2-21	Dry run, 100% TIT, small nozzle	11.8	0.025	Long	180	-	90	1427	12	
2-22	Dry run, part load	11.8	0.025	Long	185	-	95	1430	63	
2-22	Dry run, part load	11.8	0.025	Long	142	-	71	1276	-	
2-22	Dry run, part load	11.8	0.025	Long	101	-	42	1167	-	
2-22	Dry run, part load	11.8	0.025	Long	78.5	-	24	1130	-	Checked idle speed: smooth at 24,000 rpm
2-24	Dry run, interm. nozzle	14.0	0.025	Long	179	-	85	1335	56	
2-24	Dry run, interm. nozzle	14.0	0.025	Long	139	-	53	1197	-	
2-24	Dry run, interm. nozzle	14.0	0.025	Long	101	-	37	1087	-	
2-24	Dry run, interm. nozzle	14.0	0.025	Long	54	-	-	1060	-	
2-25	Wet run, part load interm. nozzle, 1st time	14.0	0.025	Long	154	191	103	1430	18	76 gpm burner water max burn wall: 160°F
3-1	Movies	14.0	0.025	Long		-	100	Est. 1300	13	
3-7	Wet run, 100%	14.0	0.025	Long	143	190	105	1413	41	D/B fuel jets are plugging: high ΔP
3-7	Wet run, 100%	14.0	0.025	Long	125	230	90	1403	-	D/B fuel jets are plugging; high ΔP
3-8	Dry run, 100% zero water	14.0	0.025	Long	-	-	-	-	5	With dry water jacket, Twall 800°F. too hot for "O" rings
3-9	Dry run, minimum water	14.0	0.025	Long	131	194	82	-	29	23 gpm burner water found turb, wheel damage
3-10	Dry run, 90%, shakedown	14.0	0.025	Long	155		Est. 70	1313	11	New turb, wheel and brgs, very good starts

TABLE 1. DEVELOPMENT TEST RESULTS (CONT.).

Date	Purpose	Configuration			Fuel Flow (pph)		Thrust Lbs	T_{T5} Average °F	Run Time Minutes	Remarks
		Exhaust Nozzle Area Sq. In.	Fuel Jet Dia. Inch	Burner	Eng.	D B				
3-11	Wet run, load line to 100%	14.0	0.025	Long	147	137	95	1343	48	57 gpm burner water
3-11	Wet run, load line to 100%	14.0	0.025	Long	156	202	115	1417	-	
3-11	Wet run, load line to 100%	14.0	0.025	Long	162	237	119	1453	-	
3-11	Wet run, load line to 100%	14.0	0.025	Long	-	247	122	1457	-	Shutdown for fuel leaks
3-14	Wet run, load line to 100%	14.0	0.025	Long	177	170	117	1430	100	32 gpm burner water
3-14	Wet run, load line to 100%	14.0	0.025	Long	179	186	119	1457	-	
3-14	Wet run, load line to 100%	14.0	0.025	Long	175	243	115	1443	-	215°F burner wall temp.
3-15	Wet run, check P_{S5} instru.	14.0	0.030	Long	139	147	81	1355	25	Isolated probe error.
3-17	Dry run, check P_{S5} instru.	14.0	0.030	Long	150	-	65	1280	13	
3-18	Dry run, check P_{S5} instru.	14.0	0.030	Long	-	-	73	1295	15	
3-22	Wet run, loadline from 95%	15.5	0.030	Long	144	205	134	1330	42	
3-22	Wet run, loadline from 95%	15.5	0.030	Long	146	183	125	1323	-	
3-22	Wet run, loadline from 95%	15.5	0.030	Long	137	155	93	-	-	
3-28	Dry, 90%	15.5	0.030	Long	149	-	73	1210	18	
3-29	(Wet), 90%	15.5	0.030	Long	153	205	70	1200	26	
3-30	Wet, 95%	15.5	0.030	Long	164	233	121	1373	28	
4-1	(Wet), 95%, loadline at const N	15.5	0.030	Long	150	-	73	1207	20	
4-12	(Wet), 100%, load-line, N K, check engine burner rod.	15.5	0.0301	Long	150	180	-	1237	26	
4-14	Wet, 90%, loadline at 66,000 rpm	15.5	0.030	Long	140	201	92	1370	51	

TABLE 1. DEVELOPMENT TEST RESULTS (CONT.).

Date	Purpose	Configuration: Exhaust Nozzle Area Sq. In.	Configuration: Fuel Jet Dia. Inch	Configuration: Burner	Fuel Flow (pph): Eng.	Fuel Flow (pph): D/B	Thrust Lbs	T_{T5} Average °F	Run Time Minutes	Remarks
4-14	Wet, 90%, loadline at 65,000 rpm	15.5	0.030	Long	147	232	97	1400	-	
4-15	Wet, 90%, loadline at 66,000 rpm	15.5	0.030	Long	148	198	100	1383	35	
4-15	Wet, 90%, loadline at 66,000 rpm	15.5	0.030	Long	142	178	92	1363	-	
4-20	Wet, 90%, loadline at 66,000 rpm	15.5	0.027*	Long	146	200	95	1390	44	Fuel: Auto gasoline.
4-20	Wet, 90%, loadline at 66,000 rpm	15.5	0.027	Long	148	235	100	1403	-	Resized fuel nozzle to 0.031 using No. 68 drill after run.
4-21	Dry, N_{max} to idle performance	15.5	0.031	Long	152 to 73	-	65 to 18	1528 to 1060	35	Running engine only is normal
4-26	Wet, Wf D/B at 180 pph	15.5	0.031	Long	-	-	-	-	-	D/B flame-out for unknown reason. Seems to lean out.
4-27	Troubleshoot rig for D/B flame-out	15.5	0.031	Long	150	230	-	1267	28	This was first try on JP4 fuel. Held D/B flame by increasing Wf to 220 pph. But D/B flamed-out at 170 pph.
5-2	Troubleshoot rig for D/B flame-out	15.5	0.031	Long	158	180-220	-	-	27	D/B flamed-out. Jet ΔP is low.
5-3	Troubleshoot for D/B flame-out using higher fuel tank supply pressure	15.5	0.031	Long		180-210	-	-	4	Sustained D/B run until tank press. fell from 92 psig to 83 psig. D/B fuel manifold press. 11 psig and jet ΔP 9 psi. D/B manifold press. believed too low to obtain fuel penetration; 0.031 dia. jets may be too large. Believe higher tank press. to F/M valve also helped.
5-5	Troubleshoot D/B flame-out using fuel jets resized from 0.031 to 0.026 diameter for higher ΔP and penetration Cont'd wet, 90° max, loadline at 66,000 rpm	15.5	0.026	Long	141-151	163-233	85-99	1350-1407	69	D/B performance back to normal using smaller fuel jets. Fuel is JP4. Evidently fuel is bypassing the orifice plug due to thermal expansion of the fitting.
5-5	Wet, 90% loadline at 72,000 rpm	15.5	0.026	Long	165-173	162-240	102-118	1437-1507	51	D/B flame-out problem is corrected. Jet ΔP is back to design value for desired value for desired penetration. Jet plugs will be welded shut and orifice resized to 0.030 diameter.

NOTES:

Dry run-testing without the augmentor operating.
Wet run-testing with the augmentor operating.

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